

GEOLOGY  
MANUAL

RICHARD M. FIELD



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# GEOLOGY MANUAL



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# GEOLOGY MANUAL

*AN INSTRUCTION AND LABORATORY  
MANUAL FOR BEGINNERS*

PART I  
PHYSICAL GEOLOGY

BY  
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## PREFACE

THE method of teaching illustrated in this Manual has been used in the introductory course in Geology at Princeton University for the last two years. The first complete edition of the Manual was published, in mimeograph form, in May 1925. The author has tried to use a standard nomenclature, the introduction of new terms being avoided except in the case of the sedimentary rocks. Of the large number of text-books on elementary Geology, recently published, few if any are helpful in laboratory teaching. This is for two reasons: first, because the study of minerals, rocks and maps requires carefully planned exercises; second, the exercises themselves necessitate specially written introductory matter somewhat different from that found in any of the present texts. Therefore the Manual has been written from the "laboratory" rather than from the "lecture" point of view. This naturally helps to develop uniform instruction in all laboratory divisions, and also supplies the less experienced instructors with much needed working material. It has been said that each instructor prefers to teach his course in his own way. This is commendable, to a certain extent, but "his own way" too often turns out to be largely the way he (the instructor) was taught. Many young "doctors" when they first start to teach have no conception of how their subject is taught in other institutions. Indeed many of our "brightest young instructors" have had no teaching experience whatever! This may not matter so much in the case of advanced or technical courses, but it is certainly a serious handicap in an introductory course. There appears to be no standard in the teaching of Geology, such as exists, to a certain extent at least, in the teaching of Chemistry and Physics. The author believes that this lack of standard has seriously hurt the academic prestige of Geology in many of our American universities. Finally, the author believes that some such method as followed in this Manual permits the lecturer (for the pleasure as well as the profit of those who are *required* to listen to him) to omit the more technical and overburdening details which cannot be "copied down" by a large class, and which can be learned much better from a text.

USE OF MANUAL. The material has been arranged in such a way that the student does his laboratory work in his book, with

## PREFACE

his instructions always before him. The completed exercise may be torn out and handed in at the end of the laboratory period, or if the instructor prefers, the whole book may be handed in. The first method allows the student to take his Manual with him and study it before he attends his next laboratory division. The second method has this advantage, it gives the student a complete and corrected record of his work at the end of the course, thus affording an excellent means for review before the final examination. If, in the case of the first method, the student can be induced to file and study his corrected exercises when they are returned to him he will be making the maximum use of his manual. The exercises have been written so as to allow a certain amount of variation in the work of the different divisions, from week to week or from year to year. The content of the exercises, however, is the same in each case and thus affords the opportunity of giving the same, or similar, examinations to all the divisions. Each division instructor is expected to add to, or modify, the exercises as he, or the instructor in charge, thinks best. The author believes that most of the laboratory periods should be used for *study* and not for *examination*, special emphasis being laid on *teaching*, rather than on *examination*, questions. The introduction of tests at the proper intervals will determine whether the student has really done his work or not.

New editions of the Manual will be published as our teaching experience accumulates. For this reason the author and the publisher will deeply appreciate thorough and detailed criticism, especially from those who have to teach large classes in institutions where an introductory course in Geology is *elected* by the students for *cultural* rather than for *technical* training.

ACKNOWLEDGMENTS. The author wishes to thank the instructors and graduate student-assistants who have taught in the introductory course in Geology at Princeton University, and who have done their best to test and correct the Manual "under fire." The author wishes especially to acknowledge the debt which he owes his colleague, Professor A. F. Buddington, for his original contributions to the descriptions of the topographic maps, and for his criticism of the section on Igneous Rocks. The line drawings were made by Dr. Willard B. Jewell and the author.

Princeton University  
June 1926

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## PREFACE TO SECOND EDITION

THE following subjects have been added to the second edition:

Introduction to the Chemistry of Rock Minerals; Essential characteristics of Common Sedimentary Rocks; Introduction to the Study of Economic Geology, and Exercises; Appendix, containing an alphabetical list of the material used in the course; Several new topographical maps, both described and undescribed; A plate illustrating textures and structures. The text has been rewritten or amended in several places; and the tables on Igneous and Sedimentary Rocks considerably altered.

ACKNOWLEDGMENTS. The author is particularly indebted to Professor Alfred C. Lane of Tufts College for helpful criticisms and original and practical suggestions. Mr. Elwyn Perry, Instructor in Geology, Princeton University, and Senior Assistant in the Elementary Course, has contributed the paragraphs on "Elements and Compounds." The author is also indebted to all of the Assistants in the course for helpful criticism.

Princeton University  
April, 1927

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## INTRODUCTION TO THE CHEMISTRY OF ROCK MINERALS

This brief summary is designed to meet the needs of a student of geology who has had little or no training in Chemistry, but who requires a knowledge of the fundamentals of that science in order to understand the composition of the common rock minerals.

### ELEMENTS AND COMPOUNDS:

Chemistry may be considered as the study of the constitution and interaction of the various kinds of matter. All matter is composed of about 90 *simple* substances, called *elements*, which enter into combination with each other in definite proportions and according to definite laws. The more *complex* substances so produced, by a combination of two or more elements, are known as *compounds*. All of the *common* rock minerals are compounds.

Each element has a symbol, used to facilitate the writing of the formulae (expression of the composition) of compounds. Each element has a fixed *combining power* by weight; thus a definite weight (or simple multiple of that weight) of one element will always be required to combine with different fixed weights of other elements. The combining power or weight of an element is expressed in its symbol; e.g., if the symbol of a certain element is the letter H, this letter written by itself indicates one combining weight of that element, the expression  $H_2$  or  $2H$  indicates two combining weights, etc. Only twelve elements need be considered in the study of the common rock minerals since these twelve elements compose nearly 99% of the earth's outer crust.

The names and symbols of the common rock forming elements are:

| METALS <span style="margin-left: 100px;">✓ 22</span> |    | OXIDE                | NON-METALS <span style="margin-left: 100px;">22 - 10</span> |    | OXIDE   |
|------------------------------------------------------|----|----------------------|-------------------------------------------------------------|----|---------|
| Aluminium                                            | Al | $Al_2O_3$            | Oxygen                                                      | O  | none    |
| Iron                                                 | Fe | { $Fe_2O_3$<br>$FeO$ | Silicon                                                     | Si | $SiO_2$ |
| Magnesium                                            | Mg |                      | Sulphur                                                     | S  | $SO_3$  |
| Calcium                                              | Ca | $CaO$                | Carbon                                                      | C  | $CO_2$  |
| (Sodium                                              | Na | $Na_2O$              | Chlorine                                                    | Cl | rare    |
| Potassium                                            | K  | $K_2O$               | Hydrogen                                                    | H  | $H_2O$  |

Although each chemical element has special properties of its



own, elements in general may be divided into *groups* having properties in common. This classification is especially important when based on the *affinity for combination* between various elements.

The metals form an important group of related elements. The compounds of the metals with Oxygen and water form what are known in chemistry as *bases*, hence metals are often spoken of as basic elements, and rocks in which the basic oxides, except the alkalis, predominate over the non-metallic oxides are called *basic* rocks. On the other hand compounds of the non-metallic elements, such as Carbon and Silicon, with Oxygen and water are known as *acids*, and when the oxides of these elements predominate in a rock, the geologist speaks of the rock as being *acid*, or acidic. Hydrogen, although a non-metal according to its physical properties, acts chemically like a metallic or basic element. The metals Potassium and Sodium belong to a group known as *alkalies*, and compounds in which they occur are sometimes spoken of as alkali-compounds, e.g., *alkali-feldspar*. The metals Iron and Magnesium are closely associated in many minerals and when these metals are present in considerable amount the mineral is often said to be *ferro-magnesian*. Iron is peculiar because it has two different combining weights and thus forms two different oxides  $\text{FeO}$  and  $\text{Fe}_2\text{O}_3$ .

The rock minerals for convenience may be divided into three groups:

1. Those composed of uncombined, or "native," elements of which carbon (Graphite) is the only important representative.
2. Those composed of simple compounds of either the metals or of Silicon, with either Sulphur, Chlorine or Oxygen. (Called sulphides, chlorides or oxides, respectively.)
3. Those composed of compounds of the basic oxides with the oxides of silicon, carbon or sulphur. (Called silicates, carbonates or sulphates.)

The third group is by far the most important, particularly the silicates and carbonates. The customary method of presenting the formulae of these minerals is in the form such as  $\text{Mg}_2\text{SiO}_4$  representing a magnesium silicate (variety of olivine), but the formula may also be expressed as a combination of the oxides ( $2\text{MgO} \cdot \text{SiO}_2$ ) which is preferable because it shows clearly whether the compound (mineral) is predominantly acid or basic.

## SOLUTIONS:

A solution is a homogeneous mixture of two or more compounds. Under such conditions we may say that the two or more compounds are *miscible*. Since compounds may exist in either a solid, liquid, or gaseous state, so may solutions of two or more compounds. It will be necessary for us to consider three types of solutions. 1. *Liquid Solutions*. 2. *Solid Solutions*. 3. *Undercooled Liquid Solutions*. Practically all materials form liquid solutions, but solid solutions are formed only of mixtures of certain definite, specific compounds. Most of the common minerals are solid solutions. The rock glasses, such as Obsidian (see Table p. 25) are *undercooled* liquid solutions. They have acquired rigidity (congealed) before the compounds have had time to arrange themselves as crystalline solids. The rock glasses will be considered more fully under the subject of the Igneous Rocks.

## I. LIQUID SOLUTIONS:

We are all more or less familiar with liquid solutions, such as, salt dissolved in water at ordinary temperatures. We have also probably observed that if we raise the temperature of the water it will dissolve the salt more readily. Perhaps we should say that if we raise the temperatures of both the salt and the water they will become more readily miscible. The molten material in a blast furnace, or better still, a natural molten rock, such as a lava, is a mutual solution of several compounds at high temperatures.

## II. SOLID SOLUTIONS:

Compounds which form minerals may occur as solid solutions. A solid solution is a *crystalline* and *homogeneous solid*, composed of an *intimate* chemical mixture of two or more substances. As an example of solid solutions: The *plagioclase feldspars* (p. 10) all of which have certain similar physical properties, are all solid solutions. Each variety of plagioclase is a *solid, homogeneous mixture* of definite proportions of two, definite, chemical compounds  $\text{NaAlSi}_3\text{O}_8$  (called Albite, in the crystalline state) and  $\text{CaAl}_2\text{Si}_2\text{O}_8$  (called Anorthite, in the crystalline state). A small definite amount of  $\text{KAlSi}_3\text{O}_8$  (called Orthoclase or Microcline, in the crystalline state) may also be dissolved in a plagioclase solid solution. The Pyroxenes, Amphiboles and Olivine are all complex solid solutions.

## INTRODUCTION TO THE STUDY OF MINERALS

### DEFINITION OR TERM:

A definition or term is a word, or a concise yet comprehensive phrase for a *definite conception*. Be sure that *you* have a definite conception of the terms or definitions used in this course, whether you agree with them or not. In case of doubt always consult your instructor. The mere memorization of a definition is not sufficient. You will be frequently tested as to whether or not you understand the definitions. You will learn (probably for the first time) that it is extremely difficult to make good definitions of what you see or think. On the other hand, the only test of whether you observe or think correctly is whether or not you are able to define your observations so that others will understand or appreciate them. Can you define the difference between "cramming" or tutoring to pass an examination, and *study*?

### DEFINITION OF MINERAL:

A mineral may be defined as *a natural inorganic substance having a characteristic chemical composition, sometimes a definite crystal form, and exhibiting other specific physical properties*. Minerals, like organisms, may be separated into species which are usually distinguished by their form and habit (mode of occurrence). Over one thousand minerals have been described, only a few of which, however, are so common as to form the common rocks. As it will not be feasible for you to test all the chemical properties of minerals in this introductory course, you will have to learn to distinguish your minerals by their physical characteristics alone. Of all the physical tests, probably crystal form is the most difficult for the elementary student to apply.

### CRYSTAL FORM OR SHAPE:

Most minerals have one or more crystal habits or shapes by which they are known. A paste or synthetic diamond *is not* a mineral because it is an artificial amorphous substance (without crystalline structure or natural crystal form) the faces or facets of which have been cut. Quartz *is* a mineral because it is a natural inorganic substance whose atoms are definitely ar-

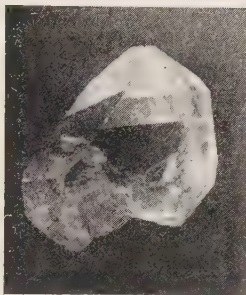


# PLATE I.



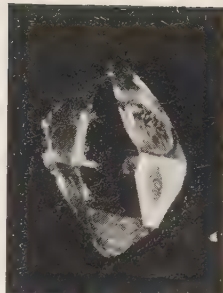
1

Nearly perfect quartz crystal showing six-sided prism capped by six-sided terminations. (+ and - rhombohedrons).



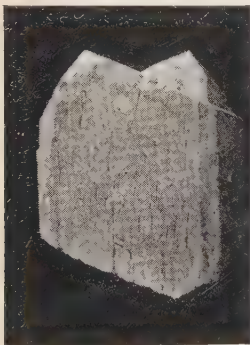
2

Imperfect twins. Smaller twin shows conchoidal fracture.



3

Imperfect quartz crystal showing distorted faces.



4

Orthoclase crystal, Carlsbad twin.



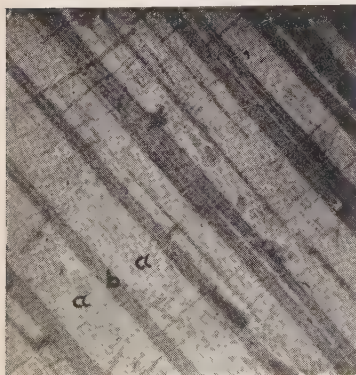
5

Simple orthoclase crystal. Note form, and rectangular cleavage on front face.



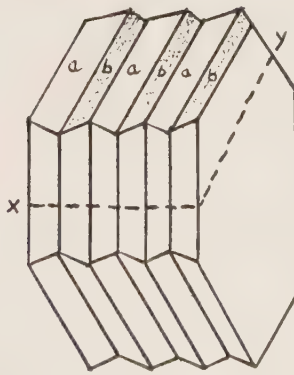
6

Orthoclase crystal Carlsbad twin.



7

"Thin section" of albite (highly magnified) showing twinning.



8

Enlarged diagram of multiple twin of plagioclase showing cause of striations. If light is shining from N.W. a faces will flash. Reversal of light or specimen will cause b faces to flash. The "thin section" shown in fig. 7 was cut along the plane x, y.

ranged; and the characteristic crystal forms such as the six-sided prism and termination are the result of this arrangement of the atoms (*Plate I, fig. 1*). Thus a mineral is usually a solid, generally bounded by crystal faces which are the result of the *growth* of the substance or crystal. Obviously, glass which has been cut in the shape of quartz is not a crystal or a mineral in a scientific sense. Every mineral, therefore, not only has a definite chemical composition, but also tends to develop a definite symmetrical shape. Unfortunately minerals, like human beings, rarely attain perfection. This is largely due to such environmental conditions as conflict and crowding which usually seriously interfere with the complete normal development of any single individual (*Plate I, fig. 2*). Fortunately, however, even when the crystal is poorly developed, you may be able to determine its ideal form and thus the species to which it belongs. A great number of crystal forms have been described and figured, and all of these forms have been found to fit into six systems. The proper study of these systems requires a thorough training in crystallography, a special phase of mineralogy. In the small amount of time allotted to the study of minerals in a general introductory course you will not have time to study crystallography. In the following brief descriptions of the common and important rock-forming minerals, you will only consider the outlines or angles of some of the typical forms.

#### LABORATORY METHOD:

The proper study of minerals requires careful qualitative and quantitative tests which, in turn, require special training. Students who find that they are interested in this phase of geology should elect a course in descriptive and determinative mineralogy. This course is also helpful for those who are taking chemistry. Fortunately there are a few simple tests which are sufficient, when carefully applied, for the determination of the common minerals. Briefly, these tests are as follows: 1) form or shape, 2) cleavage, 3) fracture, 4) surface markings, 5) hardness, 6) color, 7) luster, 8) reaction with acid ( $\text{HCl}$ ), 9) heft. When applying the following physical or optical tests you must be careful to determine whether you are examining a *single mineral* or an *aggregate of similar or dissimilar minerals*. You must train your eye to distinguish cleavage faces. This, of course, becomes more difficult in the fine-grained igneous and



metamorphic rocks where the different minerals are interlocking and have somewhat the same color and luster. It often takes keen eyesight to distinguish the boundaries between individual grains of dark minerals, such as pyroxene, hornblende and biotite, or of the light minerals, such as the more glassy forms of feldspar, and quartz. The description of an object requires keen and careful observation, *which is the basis of all scientific work. If you have not already cultivated this ability, do so as soon as possible.*

### PHYSICAL TESTS:

The nine important physical tests previously named are described below. The only equipment necessary for the application of the tests is: 1) knife or small file, 2) glass scratch-plate, 3) porcelain scratch-plate, 4) small magnifying glass, 5) small bottle of hydrochloric acid ( $\text{HCl}$ ). A set of ten minerals illustrating the scale of hardness is useful but not absolutely necessary.

#### 1 - CRYSTAL FORM: - typically crystal-looking

Many of the crystalline minerals, such as quartz, may be identified by their shape. This will be discussed and illustrated in the laboratory demonstration.

#### 2 - CLEAVAGE:

This is the property of minerals to break or split more easily in certain directions. The planes are parallel to each other and also parallel to some crystal face. Thus the mineral galena ( $\text{PbS}$ ) or calcite ( $\text{CaCO}_3$ ) cleaves readily into any number of individuals, sometimes similar in shape to the original crystal. Cleavage surfaces flash when held at the proper angle to the light, and may be discovered by this method even when exceedingly small.

#### 3 - FRACTURE:

This is the property of minerals to break with a curved or uneven surface. A mineral (quartz) may show fracture only, or (feldspar) both fracture and cleavage, or (galena) cleavage and no fracture. The different types of fractures are (a) conchoidal or shell-like, (b) uneven or rough, (c) smooth, (d) earthy.

#### 4 - SURFACE MARKINGS:

Certain cleavage surfaces or the crystal faces of some crystals

show peculiar surface markings, i.e., *striae* on the prism faces of plagioclase feldspar which look like fine parallel lines ruled with a diamond point (*Plate I, figs. 7-8*). Quartz and calcite crystals often have surface markings which must not be confused with the typical striae on plagioclase.

### HARDNESS:

This may be defined as a mineral's resistance to abrasion or scratching. When applying this test you must be sure that you are really scratching the mineral and not breaking it. Also, when scratching one mineral with another mineral or with a knife or scratch-plate, be sure that you do not mistake a mark of the softer substance upon the harder one for a scratch, i.e., when trying to scratch quartz with a knife the latter often leaves some of the steel in the form of a black mark on the quartz which may look like a scratch. The list of ten minerals which follows is called Moh's scale. These minerals are arranged in the order of increasing hardness, as follows:

- |                        |              |
|------------------------|--------------|
| 1. talc                | 6. feldspar- |
| 2. gypsum              | 7. quartz    |
| 3. calcite - limestone | 8. topaz     |
| 4. fluorite            | 9. corundum  |
| 5. apatite             | 10. diamond  |

Talc (1) may be scratched with the flesh, gypsum (2) with the finger nail, calcite (3) with a knife or copper coin, orthoclase\* (6) with quartz. Quartz (7) is the hardest of the common minerals, but is exceeded by topaz (8), corundum (9) and diamond (10). Thus a knife will scratch minerals of hardness 5 or less. Minerals of 6 or greater hardness will scratch glass. The micas may be scratched with a copper coin.

### COLOR:

The same mineral may have *one or several different colors*. When the mineral is soft it may be tested by its streak on the porcelain plate. Color is not always a safe criterion for the determination of mineral species, but *streak* (which is the color of the powdered mineral) *usually is*.

### LUSTER:

The appearance of the surface of a mineral in reflected light. Non-metallic minerals are either lusterless or vitreous (glassy), etc.

\*A mineral with a greater hardness than 5 will scratch glass.

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### REACTION WITH HCl:

When a drop of acid is placed on the mineral calcite, or limestone, it effervesces (gives off  $\text{CO}_2$  gas). Dolomite will react with acid only if powdered or scratched. The acid test is especially useful in determining shaly limestones from the clay rocks or shales. It is also useful for determining whether or not a sandstone has a calcareous cement.

### HEFT:

The specific gravity or relative weight of a mineral.

### INSTRUCTOR'S REMARKS

quartz - very good sample.  
feldspar - 1 piece of cleavage at 45°

1. quartz
2. feldspar
3. pyroxene
4. amphibole
5. biotite
6. hornblende
7. calcite
8. dolomite
9. gypsum
10. halite

## ESSENTIAL CHARACTERISTICS OF COMMON MINERALS IN IGNEOUS ROCKS

### QUARTZ:

Silica ( $\text{SiO}_2$ ). A common mineral in most of the light-colored igneous rocks and the chief mineral of sandstones. The crystal form is usually not easy to determine, especially in some fine-grained rocks and massive veins, where it often occurs as shapeless masses due to the fact that it has been one of the last minerals to crystallize out of the original solution or magma. (*Plate I, figs. 1, 2, 3*). Quartz is the hardest (7) of the common minerals. It has no cleavage, but a rough or shell-like fracture (*Plate I, fig. 2*). The color of quartz is quite variable—white, black, brown, yellow, rose, and amethyst. The luster of a crystal face is glassy, while that of a fractured surface is often characterized as greasy. You must learn to distinguish between the glassy or greasy luster of the fractured surface of quartz and the reflection of light from the cleavage faces of feldspar. The best test for small, shapeless grains is *hardness* and lack of cleavage; also the quartz grains absorb the light more readily and therefore appear darker than the light-colored feldspars. On weathered rock surfaces the quartz is less altered than the other light-colored minerals, such as the feldspars.

### FELDSPAR GROUP:

A common mineral in all of the light-colored, and present in most of the dark-colored, crystalline rocks. The term feldspar is a family name for a large number of species which comprise altogether probably over 50 per cent of all the species of rock-forming minerals. The common feldspars are all silicates of aluminum and either potassium (K), sodium (Na) and calcium (Ca) or their mixtures. If the feldspar contains potassium (K) or sodium (Na), or both, it is said to be *alkalic*. The alkalic feldspars include *orthoclase* (potassium feldspar) and *albite* (soda feldspar), which is one of the plagioclases. The former is more common. If the feldspar contains calcium or calcium + sodium ( $\text{Ca} + \text{Na}$ ) it may be called plagioclase. Since you will be unable to determine the chemical composition of the feldspars and will have to rely upon the physical determinations, as



described below, you must remember that one of the plagioclases, albite ( $\text{Na}^+$ ) is an alkalic feldspar. It is helpful to know that the plagioclases are cream-colored or greenish. The crystal forms of the plagioclases are altogether too complicated to be discussed in this course. Further, the crystal forms are usually too small or too poorly developed in the igneous rocks to be identified with the naked eye. You will have to rely principally upon the following tests:

1. All feldspars have a hardness of 6.
2. All feldspars have two good cleavages at, or nearly at, right angles, one of which may be distinguished even in fairly fine-grained rocks.
3. For possible confusion of light, glassy feldspars with quartz, see remarks under the description of the latter mineral.

ORTHOCLASE: (*Plate I, figs. 4, 5, 6*) - *alkalic*

( $\text{KAlSi}_3\text{O}_8$ ) Potassium alkaline feldspar. Color cream, gray or pink, usually the latter. Cleavage surfaces *never show striations*. (See surface markings, p. 7.) A common mineral in alkaline rocks (rich in aluminium (Al), potassium (K) and silica ( $\text{SiO}_2$ )).

PLAGIOCLASE: (*Plate I, figs. 7, 8*)

A chemically variable group of calcium or sodium, or calcium and sodium aluminium silicates. Color extremely variable. One of the cleavage surfaces should *show striations*. A common constituent of the basic rocks (rich in the ferro-magnesian and calcium minerals) except albite, which is an alkaline feldspar. Varieties: albite, oligoclase, andesine, labradorite. *Orthoclase* is rare in rocks containing over 30 per cent of pyriboles and, if present, is usually associated with square, chunky crystals of quartz. The plagioclases are most abundant, as elongated plates, in rocks rich in pyriboles and poor in quartz.

MICA GROUP: (*Plate II, fig. 5*)

Aluminium silicates plus potassium or potassium and the ferro-magnesian molecule. One species (lepidolite or lithia mica) contains lithium and potassium. Micas are found in most of the crystalline rocks. The crystal form is difficult to determine, except that the basal section looks like a six-sided polygon. Mica has the most perfect cleavage known, parallel to the base. The cleavage fragments are not only flexible, but

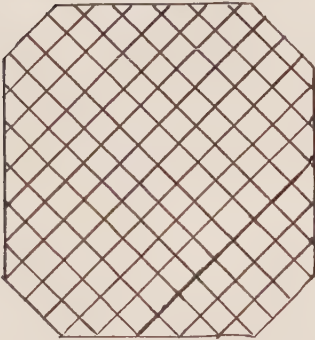
PLATE II.



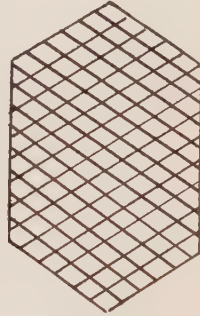
1  
Pyroxene crystals (augite).



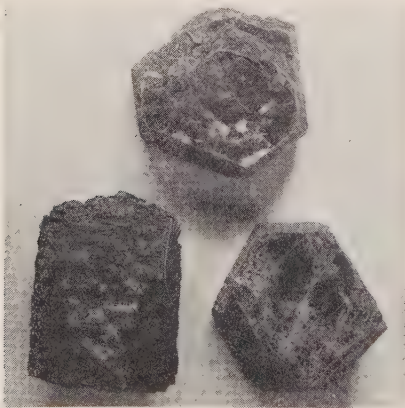
2  
Amphibole crystals (actinolite) in talc.



3  
Cross-section of pyroxene crystal showing approximately rectangular cleavage (magnified).



4  
Cross-section of amphibole showing diamond shaped cleavage (magnified).



5  
Side and top view of mica crystals. Note cleavage.



6  
Olivine crystals.

Figs. 1, 2, 5, and 6 from Prof. Phillips' Mineralogy. Reproduced by permission of Macmillan & Co.

also elastic. The latter feature distinguishes mica from chlorite. (See metamorphic minerals, p. 43.) Hardness 2.5 and easily scratched with a knife or copper coin.

#### BIOTITE:

Iron-magnesian mica. Brown to black. When in small grains may be distinguished from the pyriboles (pyroxene and amphibole) by its softness, more perfect cleavage, and peculiar luster.

#### MUSCOVITE:

Potash mica. Similar to biotite except that it is lighter colored or even white. When in small grains, muscovite may be distinguished from light-colored feldspar or quartz by its perfect cleavage (minute flakes are easily pried off with the point of a knife), and softness.

#### PYRIBOLE GROUP:

The term used in this course for a number of dark green to brown, usually black, iron magnesian-calcium silicates which are difficult to determine when occurring as small grains. Common in the alkali-siliceous igneous rocks, but preponderant in the ferro-magnesian rocks. Hardness 5-6. Distinguished from biotite by luster, hardness, and splintery cleavage which is not so perfect as the platy cleavage of black mica.

#### PYROXENE: (*Plate II, figs. 1, 3*)

Usually short and stout, eight-sided Pyriboles with the characteristic rectangular cleavage, as shown in *Fig. 6*. Cleavage approximately at right angles, or  $87^\circ$ . The common variety of Pyroxene is AUGITE.

#### AMPHIBOLE: (*Plate II, figs. 2, 4*)

Similar to pyroxene except that the crystals are six-sided and the cleavage surfaces or planes meet at angles of  $56^\circ$  and  $124^\circ$ . Thus amphibole will always have one cleavage angle greater than  $90^\circ$  (*Fig. 4*.) The common variety of amphibole is HORN-BLENDE.

#### OLIVINE: (*Plate II, fig. 6*)

Magnesian-iron silicate. Occurs as grains or stubby crystals in the iron-magnesian rich rocks (dark, heavy rocks). The crystal form may usually be distinguished with a hand lens. Color, pis-

## GEOLOGY MANUAL

tachio or yellow-green. Luster, vitreous. Poor cleavage and conchoidal fracture. Usually occurs as small irregular grains; thus a hand specimen is apt to be an aggregate of many small crystals. The color of this mineral is quite distinctive and will usually serve to distinguish olivine from any of the other common rock-forming minerals except epidote. The hardness and fracture tests are also important. Hardness 6.5 +

### INSTRUCTOR'S REMARKS

# LABORATORY BLANK

## ESSENTIAL MINERALS IN IGNEOUS ROCKS

| NO. | SHAPE    | COMPOSITION* | COLOR and LUSTER      | HARDNESS | CLEAVAGE       | FRACTURE   | NAME                                      | OTHER OBSERVATIONS                                                     |
|-----|----------|--------------|-----------------------|----------|----------------|------------|-------------------------------------------|------------------------------------------------------------------------|
| A4  | sheet    | basic        | black<br>non-metallic | 2.5      | none known     | rough      | biotite                                   |                                                                        |
| A5  | "        | "            | non-metallic          | 2.5      | "              | "          | muscovite                                 |                                                                        |
| A4  | rocky    |              | red                   | 6        | 2 cleavages    | smooth     | plagioclase                               | dark                                                                   |
| A2  | rocky    | "            | red                   | 6        | "              | "          | orthoclase                                | no twinning                                                            |
| A8  | crystals | "            | non-metallic<br>green | 6.5      | no             | conchoidal | olivine                                   |                                                                        |
| A6  | l.       | basic        | black<br>metallic     | 5        | 2 faces at 90° | rough      | pyroxene                                  | isomorphous - 97°                                                      |
| A7  | +        | basic        | black<br>metallic     | 5        | 1 face         | rough      | pyroxene<br>and plagioclase<br>hornblende | should show 2 cleavage<br>faces meeting at 60.5° + 124°<br>but doesn't |
| A1  | crystal  | basic        | white<br>non-metallic | 7        | "              | "          | quartz                                    |                                                                        |
|     |          |              |                       |          |                |            |                                           |                                                                        |
|     |          |              |                       |          |                |            |                                           |                                                                        |

\* Acid or basic ?



NAME

DIVISION

DATE

## GEOLOGY MANUAL

### LABORATORY EXERCISES ON IGNEOUS ROCK MINERALS

EXERCISE A. Study the named minerals in the tray using the "Introduction to the Study of Minerals" and the "Essential Characteristics of Common Minerals in Igneous Rocks." *Be sure that you understand all the terms* used in the text. You will be examined later as to your knowledge of these minerals.

or

EXERCISE B. Identify the numbered (unnamed) minerals in the trays using the "Introduction to the Study of Minerals" and the "Essential Characteristics of Common Minerals in Igneous Rocks." Enter your conclusions on the laboratory blank, facing p. 14.

or

EXERCISE C. Describe and name the minerals in your trays (without reference to the text). Enter all your conclusions on the laboratory blank, facing p. 14.

### TEST QUESTIONS

1. What is a mineral?
2. Define the following terms: Crystal form, cleavage, fracture.
3. Define the scale of hardness.
4. How would you tell white quartz from "glassy" feldspar?
5. How would you distinguish between the three dark minerals: biotite, augite and hornblende?
6. Name the common minerals in igneous rocks.

*Micas (biotite, muscovite), Pyroxenes (pyroxene & amphibole)*

### INSTRUCTOR'S REMARKS

## INTRODUCTION TO THE STUDY OF IGNEOUS ROCKS

### DEFINITION OF A ROCK:

A rock may be defined as a *fairly large unit of the earth's outer shell*. By "fairly large unit" is meant that it occurs as large and relatively uniform masses or bodies, composed of one or more substances. Technically, the above definition includes such diverse substances and aggregates as sand, sandstone, water, ice, volcanic ashes, tuff, obsidian, granite, and coal. Thus liquids, unconsolidated and consolidated materials, crystalline and non-crystalline materials, as well as organic substances, when forming a sizable unit of the earth's outer shell, may be considered rocks. In the laboratory, however, we shall confine the term to *consolidated or lithified* (turned to stone) or *coherent material*. The study of such substances is called *Petrology*.

### DEFINITION OF IGNEOUS ROCK:

Igneous rocks may be defined as *rocks which have solidified, with cooling, from magma or lava* ("deep-seated" or volcanic, natural, complex liquid solutions at high temperature) *with or without actual or apparent crystallization*. *Magma* is molten material which has not reached the surface of the earth and which retains original gases in solution under great pressure and relatively impervious cover. *Lava* is molten material which has been poured out at the surface of the earth and, due to the relief of pressure, has lost much of its water and other volatile constituents before solidification. With the exception of the comparatively rare rock glasses, an igneous rock may be said to be an *aggregate of one or more* (usually several) *minerals which have crystallized from a magma or lava*.

### EVOLUTION OF IGNEOUS ROCKS:

In biology (study of organisms) animals and plants of diverse physical characters and chemical composition are interpreted as being genetically related and thus are supposed to have evolved in ever broadening or divergent lines from a common ancestor. Such is the organic "tree of life." In petrology, rocks of diverse chemical composition and physical char-

acter are supposed to have evolved, through a process of differentiation, from a magma or common complex solution comprised mostly of silicates with some gas in solution. Experiments suggest that such chemically or mineralogically dissimilar rocks as peridotite, anorthosite, diorite, granite and syenite (see Table, p. 25, and Supplementary List of Igneous Rocks, p. 26) may have been progressively derived from a magma of gabbroic character by the successive separation of crystals from the gradually cooling "mother liquor." Just as no biologist questions the fact of the evolution of organisms, so no geologist questions the fact of the evolution of the igneous rocks; but the way in which their evolution has taken place, and especially the causes of their evolution, is still not definitely known. We do know, however, that given a magma of definite chemical composition, the structure and texture of its resultant rock species will vary considerably according to the conditions under which it solidified. Thus, if a magma cools very slowly, under great pressure, well below the earth's surface, the crystallized product will have quite a different physical composition from one which has cooled and solidified rapidly at or near the earth's surface. Igneous rocks vary from coarse-grained (pegmatite), in which the individual crystals may be a foot or more in diameter, to a dense rock (felsite) in which the individual crystals are so small that they cannot be seen by the naked eye (*Plate IV, fig. 1*), and in some cases even to obsidian with practically no crystallization. The felsites are told from rock glass (obsidian), which is non-crystalline, by their stony appearance. If we consider the field relationships or environmental conditions under which each species solidified, we find that the medium-grained types (granitoid) usually occur in large masses of unknown depth and wide surface area (batholiths) (*Plate III, fig. 5*), while the fine-grained types (felsitic) occur in lava flows, cross-cutting sheets (dikes) (*Plate III, fig. 3*), relatively small tabular and lens-like bodies (sills) (*Plate III, fig. 1*), or mushroom-shaped bodies (laccoliths) (*Plate III, fig. 2*), the latter often of considerable size. Both the sills and laccoliths are intruded into sedimentary rocks parallel to the bedding, or other structure, whereas the dikes are cross-cutting. (See figures of above forms.) Finally, the glassy-textured types are commonly restricted to the top or bottom of surface lava flows or to the chilled edges of small masses of igneous rocks. Thus the more

# PLATE III.

## FIELD RELATIONSHIPS AND FORMS OF THE INJECTED AND DEEP-SEATED ROCKS.

A. CONCORDANT. Intrusion parallel to the stratification of the sedimentary rocks.

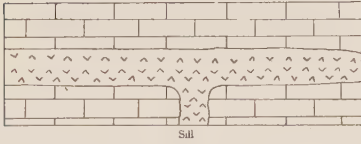


Fig. 1

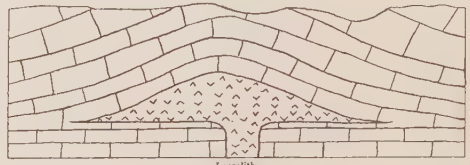


Fig. 2

B. DISCORDANT. Intrusion, non-parallel, or crosscutting the stratification of sedimentary rocks, or the foliation of metamorphic rocks.

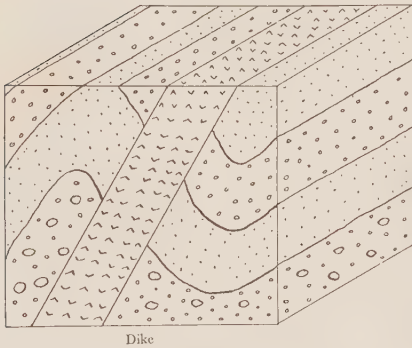


Fig. 3

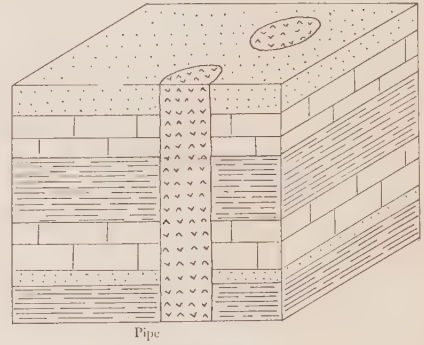


Fig. 4

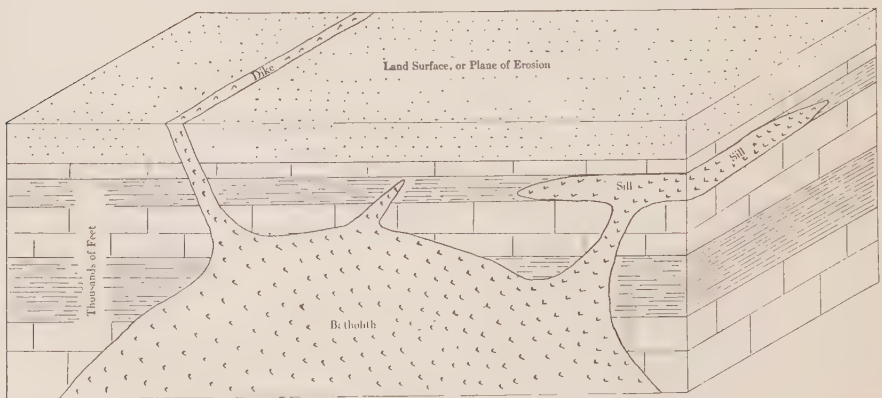


Fig. 5



slowly the magma cools the coarser the texture, the more quickly the magma cools the finer the texture, the most rapid chilling not permitting crystallization at all, but producing a glass or *undercooled, liquid solution* (see p. 3). The field observation is confirmed by experiment in the laboratory. If gabbro is melted and chilled quickly, the result is a very black glass similar to tachylite. If granite is subjected to the same process, the result is a glass similar to obsidian. Unfortunately it has not yet been possible to reverse the process; first, because we cannot get the original magma from which granite has crystallized; second, because we cannot cool the solution slowly enough under great enough pressure. You must remember that the above generalization does not by any means take into consideration all of the textures and structures in igneous rocks nor the conditions governing their origin. You should appreciate, however, after studying the laboratory material, that rocks are highly "personable" and therefore readily classified; further, that the proper classification of the igneous rocks depends fully as much upon their origin and evolution as does the classification of animals and plants.

But, like the several theories as to the causes of the evolution of organisms, we do not know yet just what are the causes of rock differentiation. So much, however, is already known about the field relationships and compositions of the igneous rocks that petrologists are able to recognize petrographic provinces in each of which occurs a group of related rock species. Thus it may be truly said that there is "blood relationship" between the igneous rocks as well as between animals; and that the chemical and mineral composition of an igneous rock is an expression of its *heredity*, the texture and structure an expression of its *environment*.

#### CLASSIFICATION OF IGNEOUS ROCKS:

Petrologists have described over 700 species of igneous rocks, of which a few are given in the table on page 25. This table is intended to illustrate the elementary *principles* of the evolution and classification of the igneous rocks and does not pretend to be comprehensive. The Granodiorite group has not been included because it tends to confuse the beginner. A glance at the table will show that the igneous rocks are classified according to both their mineral (chemical) composition and physical characteristics. It has been already pointed out that rocks having

approximately the same chemical composition are often quite dissimilar physically. The physical characteristics are by some authorities described under texture and structure. In this course we shall define *structure* as the arrangement of the constituents (mineral grains) and *texture* as the comparative size of the constituents (both in the same specimen and in different specimens). You are warned, however, that there is considerable disagreement among petrologists as to the exact use of these terms. When rocks are composed principally of one mineral they are called *monomineralic*. *Pyroxenite* and other relatively rare, basic igneous rocks fall in this class. *Anorthosite* (composed principally of plagioclase feldspar) has no effusive equivalent and is so peculiar in many respects that it does not fit well into the table on page 25.

The following outline illustrates a method for the macroscopic determination of a rock species. You should use it when you are studying described material, or for identifying unknown material. The names of the common rocks, together with their characteristics, are listed in the table on page 25. Only the common textures and structures are listed below. More may be added if desired. For illustrations of two important textures and structures described below, see *Plate IV*—*a, b*.

## INSTRUCTOR'S REMARKS

## MICROPHOTOGRAPHS OF IMPORTANT TEXTURES AND STRUCTURES

These photographs have been taken by transmitted light. A thin section was made from each rock by cutting a thin slice with a diamond saw, and then grinding the slice down to 1/1000 of an inch thick. This thin, transparent section was then photographed through a petrographic microscope. The petrographic microscope differs from an ordinary magnifying lens in that (1) the light is passed through the object to be examined instead of being reflected from its surface; (2) the rays of light or image may be altered or tested by means of special apparatus.

1. Microphotograph (enlarged 10 times) of a felsite-porphyry showing a fine grained, crystalline matrix and phenocrysts of biotite. The matrix of this species appears stony in the hand specimen, and is not easily distinguishable even with a magnification of 10 times.

2. Microphotograph (enlarged 10 times) of a flow-felsite, or flow-breccia. The individual grains (crystals) of the matrix or "ground mass" are not clearly distinguishable even with a magnification of 10 times.

3. *Granitic Texture.* x 18.

The mineral grains are interlocking, approximately the same size, and show no particular arrangement.

4. *Diabasic Texture.* x 18.

The texture is decidedly porphyritic. The phenocrysts of feldspar are lath-shaped, but have no particular arrangement such as they would have if the rock exhibited flow structure.

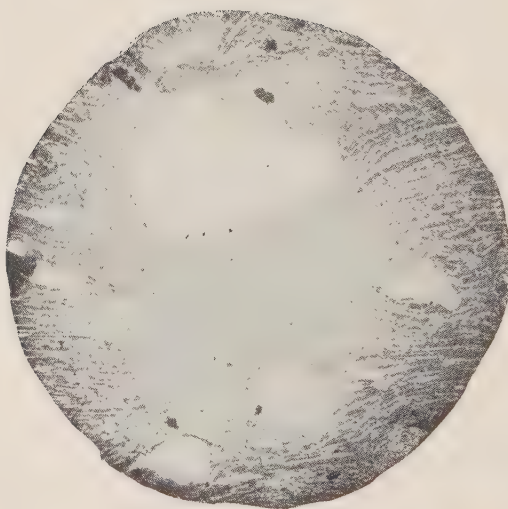
5. *Schistose Texture.* x 18.

The light and dark minerals are concentrated in wavy bands. This type of banding is called foliation and differs from bedding or stratification in that the bands are seen to be made up of crystals, not clasts (water-worn fragments).

PLATE IV—*a.*



1



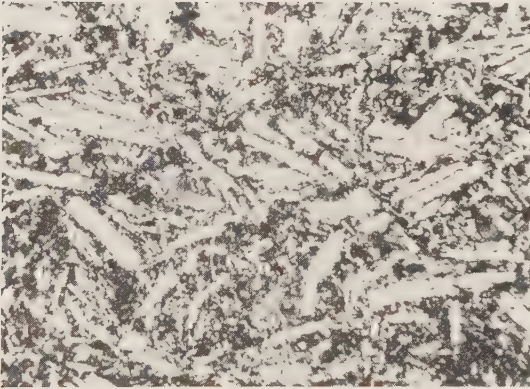
2



PLATE IV—*b.*



3



4



5



## GEOLOGY MANUAL

### MACROSCOPIC DETERMINATION OF IGNEOUS ROCKS<sup>1</sup>

#### I. TEXTURE. Absolute and relative size of mineral grains.

##### A. *Even-grained.*

- 1) Fine or felsitic (indistinguishable, "stony" appearance.) (average size  $< 1$  mm.)
- 2) Medium or granitic. (1-5 mm.)
- 3) Coarse or pegmatitic. ( $> 5$  mm.)

##### B. *Uneven-grained.*<sup>2</sup>

- 1) Porphyritic. The large crystals are called *phenocrysts*, meaning "show-crystals," and are surrounded by a matrix of smaller grains.
- 2) Felsitic-Porphyritic. The phenocrysts are surrounded by a *matrix* of very fine or invisible mineral grains.
- 3) Amygdular. The large almond-shaped mineral aggregates are called amygdules, and are surrounded by a matrix of very fine or invisible mineral grains.

#### II. STRUCTURE. Arrangement of grains or constituents.

##### A. *Arrangement of mineral species.*

- 1) Scattered or mixed.
- 2) Banded: Flow and Flow-breccia.

##### B. *Arrangement of gas holes (vesicles).*

- 1) Scattered or mixed.
- 2) Banded: Flow.

#### III. MINERAL COMPOSITION. In order to name the rock (see table) the minerals must be determined if possible but when the grain of the rock is so fine that the minerals are indistinguishable the rock is called a *felsite* if it is *light colored* or a *basalt* if it is dark colored. See pp. 26 and 27.

<sup>1</sup> Rock glasses (obsidian and tachylite) may have no texture or structure, and may be considered as under-cooled solutions.

<sup>2</sup> In the case of the uneven-grained or porphyritic rocks they are named according to the composition of the matrix, i.e. Granite Porphyry or Felsite Porphyry.

# GEOLOGY MANUAL

## TABLE OF COMMON IGNEOUS ROCKS\*

| MODE OF OCCURRENCE<br><br>(read across) |                                                                         |                                     | Rate of cooling, slow to rapid<br>→                                                |                                             |                           |                                                                       |                                    |
|-----------------------------------------|-------------------------------------------------------------------------|-------------------------------------|------------------------------------------------------------------------------------|---------------------------------------------|---------------------------|-----------------------------------------------------------------------|------------------------------------|
|                                         |                                                                         |                                     | Commonly as batholiths, stocks or laccoliths                                       | Commonly as dikes, sills, or surface flows. |                           | Commonly as flows, or along edges of sills, or blown out of volcanoes |                                    |
| I                                       | TEXTURE<br><br>(read across)<br><i>comparative size of constituents</i> |                                     | EVEN grain, medium or coarse or UNEVEN grain, Porphyritic<br>1- grain, Porphyritic | UNEVEN grain, Porphyritic<br>2-Felsitic     | EVEN grain, 1-Felsitic    | NO texture, Amorphous or texture subordinate                          |                                    |
| II                                      | STRUCTURE<br><br>(read across)<br><i>arrangement of grains</i>          |                                     | SCATTERED or mixed, rarely flow (1)                                                | SCATTERED or mixed or flow (2)              | SCATTERED, often flow (3) | NO structure or mixed or flow (4)                                     |                                    |
| III                                     | MINERAL COMP.                                                           |                                     | Decreasing size of particles<br>→                                                  |                                             |                           |                                                                       |                                    |
|                                         | ESSENTIAL Minerals                                                      | OTHER Minerals                      | Increasing amount of glass<br>→                                                    |                                             |                           |                                                                       |                                    |
|                                         | quartz and alkalic feldspars                                            | mica-hornblende plagioclase         | *GRANITE (PEGMATITE) (PORPHYRITIC GRANITE)                                         | light colored rocks                         | *FELSITE PORPHYRY         | *FELSITE                                                              | OBSIDIAN (dark) and PUMICE (light) |
|                                         | alkalic feldspars and pyribole                                          | mica plagioclase-quartz             | SYENITE                                                                            |                                             |                           |                                                                       |                                    |
|                                         | plagioclase amphibole                                                   | mica, alkalic feldspar and pyroxene | DIORITE or GABBRO                                                                  | dark colored rocks                          | BASALT PORPHYRY           | BASALT or VESICULAR BASALT                                            | TACHYLITE and PUMICE               |
|                                         | plagioclase pyroxene                                                    | mica olivine hornblende             |                                                                                    |                                             |                           |                                                                       |                                    |
|                                         | <i>no feldspars</i><br>olivine hornblende pyroxene                      | mica plagioclase                    | PERIDOTITE                                                                         |                                             |                           |                                                                       |                                    |

NOTE: The alkali-feldspars include orthoclase and microcline (potash feldspar) and albite (soda feldspar, which is one of the plagioclases). Orthoclase or microcline are most common.

\*See page 26 for supplementary list of important igneous rocks.

## GEOLOGY MANUAL

### SUPPLEMENTARY LIST OF IMPORTANT IGNEOUS ROCKS

#### I. ACID EFFUSIVES:

Felsite is a general and very useful term for a fine-grained, light-colored, effusive or intrusive phase of granite or syenite in which the minerals are indistinguishable. If the minerals are distinguishable with the naked eye or with the help of a lens or microscope the rock may be identified as either one of the following:

##### RHYOLITE:

A volcanic rock often porphyritic in texture, with phenocrysts of quartz and orthoclase. Often shows flow structure, especially when fine-grained. The term rhyolite is often used both for rhyolite proper and obsidian. Most felsites are apt to be rhyolites. Extrusive phase of granite.

##### DACITE:

A quartz-bearing andesite. Approximately the same chemical composition as a quartz-bearing diorite. Commonly has phenocrysts of quartz and plagioclase.

##### TRACHYTE:

A volcanic rock, often porphyritic in texture, and essentially composed of alkalic feldspars, and one or more of the ferro-magnesian minerals (biotite and augite). Extrusive phase of syenite.

#### II. BASIC EFFUSIVES:

The term basalt has been rather loosely applied to basic effusives, many of which are Andesites.

##### ANDESITE:

A volcanic, effusive or intrusive rock, usually having a porphyritic texture, and composed essentially of plagioclase feldspar and ferro-magnesian minerals. Approximately the same chemical composition as diorite.

#### III. GRANITOID OR PLUTONIC:

In western North America (North American Cordilleran) the predominating, deep-seated, or batholithic rocks are granodiorites. These rocks also have their intrusive, extrusive, and effusive equivalents and form a natural, chemically related group, which lies between the acid (Granite) group, and the

## GEOLOGY MANUAL

more basic (Diorite) group. (For definitions of *acid* and *basic* see p. 2.)

In terms of acidity or silica ( $\text{SiO}_2$ ) content, the igneous rocks may be divided as follows:

| ACID GROUP                       | INTERMEDIATE GROUP    | BASIC GROUP                   |
|----------------------------------|-----------------------|-------------------------------|
| (GRANITE, GRANODIORITE,<br>ETC.) | (DIORITE, ETC.)       | (GABBRO, PERIDOTITE,<br>ETC.) |
| 80-60% $\text{SiO}_2$            | 65-50% $\text{SiO}_2$ | 65-30% $\text{SiO}_2$         |

Many of the famous ore deposits are associated with the granodiorites and allied rocks.

### GRANODIORITE:

A rock having a granitoid texture and intermediate between a quartz-bearing diorite and a granite, in that it contains a relatively higher percentage of plagioclase feldspar than granite and a higher percentage of potash feldspar than quartz diorite.

### ANORTHOSITE:

A more or less *monomineralic* rock having a granitoid texture and consisting mainly of plagioclase feldspar. Anorthosite is usually exceedingly poor in the ferro-magnesian minerals, and is difficult to place in any rock classification.

### DIABASE:

Not a typical granitoid but a relatively coarse-grained rock consisting mainly of plagioclase feldspar and pyroxene, sometimes accessory olivine, and especially characterized by the fact that the small pyroxene crystals are interstitial to "laths" of plagioclase. This type of texture is called ophitic or diabasic texture. Diabase is approximately of the same chemical composition as Gabbro (*Plate IV-b 4*).

### INSTRUCTOR'S REMARKS

## GEOLOGY MANUAL

### LABORATORY EXERCISES ON IGNEOUS ROCKS

- EXERCISE A. Study the named rocks in the trays using the "Introduction to the Study of Igneous Rocks" and the "Table of Common Igneous Rocks." Be sure that you understand all the terms used in the text. You will be examined later as to your knowledge of these types.
- or*
- EXERCISE B. Identify the numbered (unnamed) rocks in the trays, using the "Introduction to the Study of Igneous Rocks" and the "Table of Common Igneous Rocks." Enter your conclusions on the laboratory blank, facing p. 28.
- or*
- EXERCISE C. Describe and name the igneous rocks in your trays (without reference to your laboratory manual). Enter all your conclusions on the laboratory blank, facing p. 28.
- (test)*

### TEST QUESTIONS

1. What is an igneous rock?
2. Discuss the method of igneous rock classification.
3. How does rate of cooling, pressure and "cover" affect the structures of igneous rocks?
4. Discuss the different field relationships and forms of injected and deep-seated (Plutonic) rocks.
5. Describe the following terms: a) texture, b) structure, c) rock glass, d) magma, e) lava, f) lithified, g) crystalline, h) solution, i) felsitic, j) granite, k) pegmatitic, l) phenocryst, m) matrix, n) amygdale, o) breccia, p) vesicle, q) solid solution, r) liquid solution, s) under-cooled, liquid solutions.

### INSTRUCTOR'S REMARKS



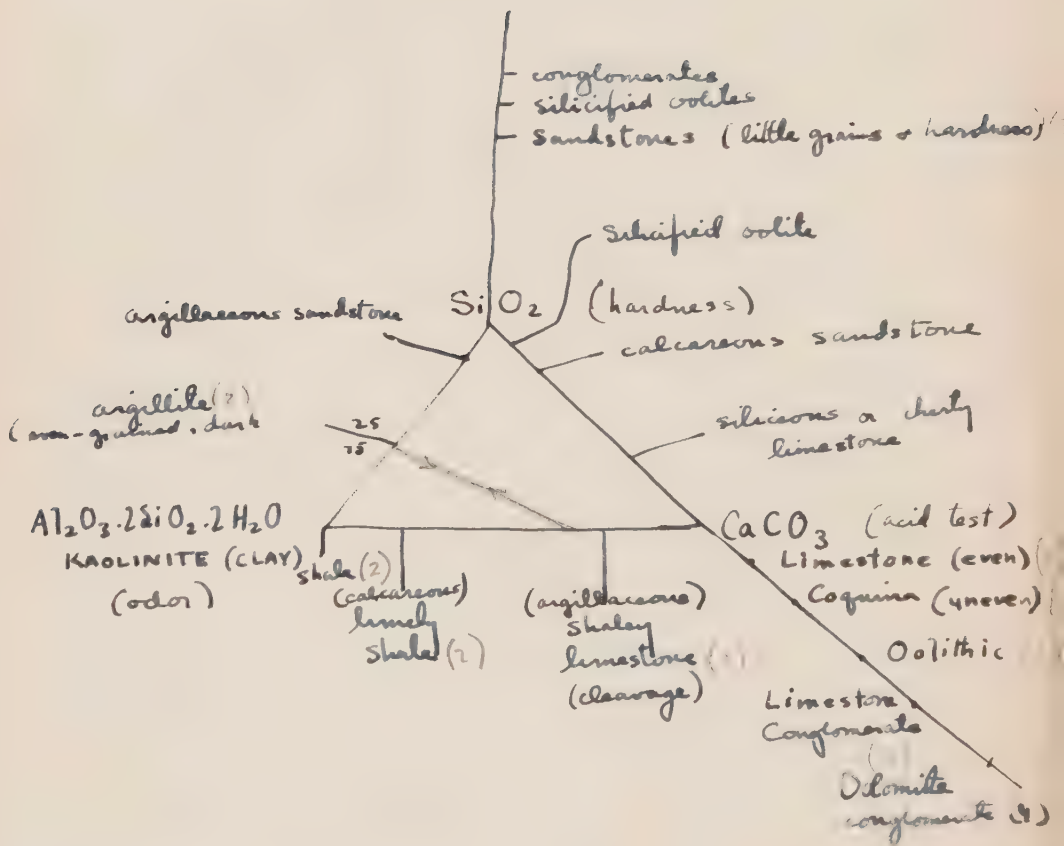
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## COMMON IGNEOUS ROCKS

| NO. | TEXTURE              | STRUCTURE | MINERAL COMPOSITION*   | NAME             | MODE OF OCCURRENCE      |
|-----|----------------------|-----------|------------------------|------------------|-------------------------|
|     | even<br>granular     | scattered | plagioclase + pyroxene | diorite          | latite, diorite, basalt |
|     |                      |           |                        |                  |                         |
|     |                      |           |                        |                  |                         |
|     | fine<br>interlocking | int       | ol.                    |                  |                         |
|     | even                 | - 11      |                        |                  |                         |
|     |                      |           | basalt - dark gray     | vesicular basalt |                         |
|     |                      | int       |                        |                  |                         |
|     |                      | int       | acidic black           | obsidian         |                         |
|     |                      |           |                        |                  |                         |
|     | even<br>fine         | fine      | red. amorphous         | basalt           |                         |

\* State color and probable chemical composition if you are unable to make out the mineral composition. Acid or Basic?

|      |         |  |                                                 |         |          |
|------|---------|--|-------------------------------------------------|---------|----------|
|      |         |  | black                                           |         |          |
| even | massive |  | quartz - in the base<br>amorphous - in the base | granite | obsidian |

$\text{SiO}_2$ 

Cementing materials:

silica - hard  
 lime - acid test  
 ferrous - green  
 clay - argillaceous odor  
 limonite - } streaks  
 hematite - }

## ESSENTIAL CHARACTERISTICS OF COMMON MINERALS IN SEDIMENTARY ROCKS

For the method of studying the sedimentary minerals, see "Introduction to the Study of Minerals," page 4. For minerals common in both sedimentary and igneous rocks (quartz, feldspar, mica, etc.), see descriptions in connection with igneous rock minerals.

### SILICA GROUP:

Oxide of silicon ( $\text{SiO}_2$ ). A common rock-forming mineral, either in the crystalline form of quartz or micro-crystalline chalcedony, or non-crystalline opal (contains water).

#### CHALCEDONY: ( $\text{SiO}_2$ ).

Occurring in kidney-shaped or concretionary masses. Hardness 7. Color white when pure. Luster waxy, transparent to translucent in thin pieces. Two important varieties are flint and chert. Varieties: agate, onyx, silicified wood.

#### FLINT: ( $\text{SiO}_2$ ).

An impure, light-colored, brown, or black chalcedony; conchoidal fracture; usually forming concretions in chalk or limestone.

#### CHERT: ( $\text{SiO}_2$ ).

Less pure varieties of flint. Color brown or black, weathering white (patina). Splintery fracture. Forms concretions in limestone and dolomite, never in chalk. *The hand specimen may react with acid due to attached or occluded calcium carbonate.*

#### KAOLINITE: ( $\text{Al}_2\text{O}_3, 2\text{SiO}_2, 2\text{H}_2\text{O}$ )

Hydrated silicate of alumina. Kaolinite is a variable component of clays. The most important source of kaolinite is the alteration of feldspars. Kaolinite occurs in many sedimentary rocks. It is a soft, earthy substance and plastic when wet; emits an argillaceous odor when breathed upon, but the latter test is not always reliable. Color, white if pure; often blue, black, green, or red, according to the nature of the impurities. Distinguish from bauxite by less permanent streak on glass.

## CARBONATE GROUP:

There are a number of carbonates which occur as minerals. The two most important carbonates in the sedimentary rocks are calcite and dolomite, both of which are important sedimentary rock-builders, especially in the older formations, and in coral reefs.

CALCITE: (*Plate V, fig. 1*)

Calcium carbonate ( $\text{CaCO}_3$ ). Occurs in well defined crystals. Other aggregate occurrences are stalactites, stalagmites, oolites, spring deposits, marine deposits both organic and inorganic, etc. Next to quartz, calcite is probably the most abundant of all minerals. Calcite may occur as six-sided prisms capped by a rhombohedron or scalenohedron (*fig. 1*). Cleavage faces are well developed in three directions at an angle of  $75^\circ$  with each other, or parallel to the faces of the rhombohedron. Hardness 3 (scratches with a knife). Color white if pure. Calcite effervesces with cold dilute hydrochloric acid. Surfaces often show peculiar markings which are not similar to the striations on feldspar. The crystal form is often difficult to determine, especially in the limestones; in this case you must rely upon the tests for hardness and noisy effervescence with hydrochloric acid ( $\text{HCl}$ ).

DOLOMITE: (*Plate V, fig. 2*)

Calcium magnesium carbonate ( $\text{CaMg}(\text{CO}_3)_2$ ). Similar to calcite but distinguished by the fact that it does not effervesce with hydrochloric acid ( $\text{HCl}$ ) unless scratched with a knife or powdered. Crystal form often indeterminate.

GYPSUM: (*Plate V, fig. 3*)

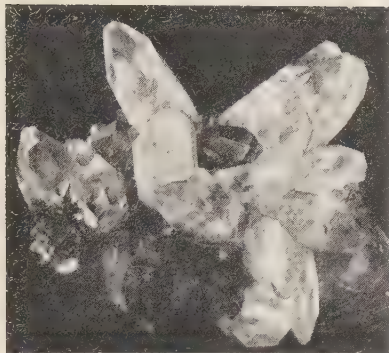
Hydrous calcium sulphate ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ). Occurs as crystals or cleavable, fibrous masses. The granular, fine-grained variety is called alabaster. The fibrous variety is called satin spar. Hardness 2 (scratches with the finger nail). Gypsum does not react with hydrochloric acid ( $\text{HCl}$ ). Gypsum is used to make plaster of Paris, stucco, etc.

## HALITE:

Sodium chloride ( $\text{NaCl}$ ), common salt. Occurs in well defined cubical crystals and in cleavable and granular masses. Hardness 2.5. Salty taste.

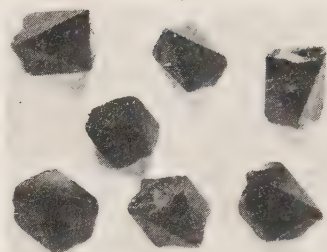


PLATE V.



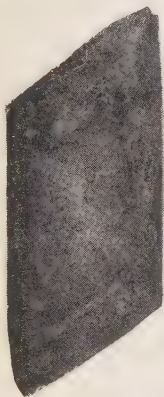
1

Group of calcite crystals. Compare with the quartz crystals on PLATE I.



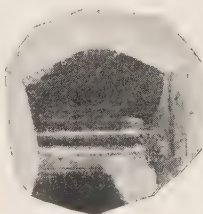
2

Dolomite crystals.

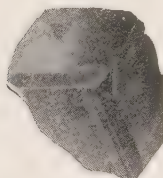


3

Two views of a well formed gypsum crystal.



a

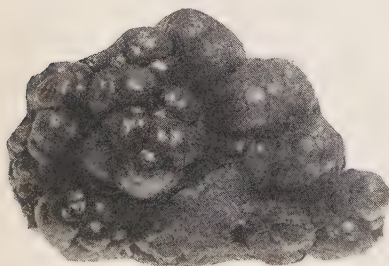


b

4

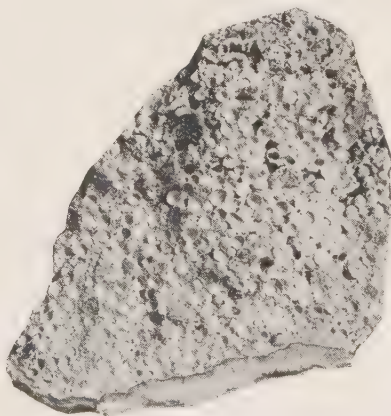
a) Pyritohedron. Notice surface markings.

b) Modified cube of pyrite.



5

Botryoidal form sometimes assumed by oxides of iron and manganese.



6

Oolite or pisolitic calcium carbonate. The indistinguishable crystal form is probably aragonite.



## IRON COMPOUNDS:

Iron compounds are common in both the igneous and sedimentary rocks. Many of the darker minerals contain iron, and it is also found as an impurity in others. The oxides of iron are important coloring agents in the sedimentary rocks. The primary iron-rich minerals are pyrite, magnetite, olivine and the silicates. As some iron compounds are soluble in water, long leaching of the primary ores and deposition elsewhere of the resultant oxides has developed ore bodies in which the ratio of iron (Fe) to the impurities, principally silica ( $\text{SiO}_2$ ) and oxygen (O), is high enough to warrant mining and smelting.

↓ **MAGNETITE:**

Iron oxide ( $\text{Fe}_3\text{O}_4$ ). Magnetic iron ore. Occurs as octahedrons, which resemble four-sided, double pyramids; and also as twelve-sided forms (dodecahedrons). Hardness 6. Color black, also showing a black streak. Metallic luster. Magnetic. Important constituent of magnetite sands, but of igneous or metamorphic origin.

↓ **PYRITE:** (*Plate V, fig. 4*)

Iron pyrites or "fools gold" ( $\text{FeS}_2$ ). Very common mineral; is apt to be found in all kinds of rocks. Occurs as cubes, octahedrons, and the peculiar forms known as pyritohedrons. (*Plate V, fig. 4 a*). Also occurs in more or less compact masses or as grains. Hardness 6; color brassy yellow; streak greenish black; luster metallic. When occurring in masses it may be mistaken for chalcopyrite (iron-sulphide-copper mineral) or for gold. Pyrite should be distinguished from chalcopyrite, which is golden yellow, and gold, which is both malleable and soft.

**LIMONITE:**

Hydrate of iron, iron rust, etc. ( $2\text{Fe}_2\text{O}_3 + 3\text{H}_2\text{O}$ .) Never crystalline, and may occur in a variety of shapes; i.e., compact, fibrous, oolitic, nodular, or earthy masses. A very common mineral, and an important cement and coloring matter in the sedimentary rocks. When it occurs in large quantities, it is called "bog iron ore." It also occurs in a number of other ways due to leaching and concentration. Limonite melts comparatively easily, and thus was probably the first iron ore smelted. Native iron is so rare, and so easily oxidized (changed to limonite), that it was probably unknown to ancient man. Hardness 5.5; color

## GEOLOGY MANUAL

yellowish brown or black; streak yellowish brown; lusterless or metallic to dull.

### HEMATITE ( $\text{Fe}_2\text{O}_3$ ): (*Plate V, fig. 5*)

May occur in much the same way as limonite, but is dark red to black in color and easily distinguished by its *red streak*. Specular hematite is black and crystalline. Hematite may be formed from limonite by driving off the water of crystallization. Hematite forms 90% of the iron resources of the United States, including the famous Clinton iron ore, which is oolitic. Earthy hematite is called "red ochre" and is used as a red pigment in paints. Hematite is also the coloring matter of several minerals and sedimentary rocks. In the latter it also often forms part of the cement, as in the case of some red sandstones and conglomerates. Reddish brown streak; soft.

### INSTRUCTOR'S REMARKS

## GEOLOGY MANUAL

### LABORATORY EXERCISES ON SEDIMENTARY ROCK MINERALS

EXERCISE A. Study the named minerals in the trays, using the "Introduction (study) to the Study of Minerals" and the "Essential Characteristics of Common Minerals in Sedimentary Rocks." You will be examined later as to your knowledge of these minerals.

or  
EXERCISE B. Identify the numbered (unnamed) minerals in the trays, using (study) the "Introduction to the Study of Minerals" and the "Essential Characteristics of Common Minerals in Sedimentary Rocks." Enter your conclusions on the laboratory blank, facing p. 34.

or  
EXERCISE C. Describe and name the minerals in your trays (without refer- (test) ence to, the text). Enter your conclusions on the laboratory blank, facing p. 34.

#### TEST QUESTIONS

1. What is a mineral?
2. What minerals occur only in sedimentary rocks?
3. What minerals are formed mainly of silica ( $\text{SiO}_2$ )?
4. How would you distinguish quartz, feldspar, calcite and dolomite from each other if you could not apply chemical tests?
5. Discuss the cleavage of the following minerals: quartz, calcite, orthoclase, biotite, hornblende, augite.
6. Name the principal "useful minerals" and their mode of occurrence.

#### INSTRUCTOR'S REMARKS

# LABORATORY BLANK

## ESSENTIAL MINERALS IN SEDIMENTARY ROCKS

| NO. | COMPOSITION*                                                    | COLOR                    | LUSTER      | STREAK                 | HARDNESS | CLEAVAGE                  | FRACTURE   | NAME                           |
|-----|-----------------------------------------------------------------|--------------------------|-------------|------------------------|----------|---------------------------|------------|--------------------------------|
| 9   | silicate<br>$\text{SiO}_2$                                      | black                    | dull        | no                     | 7        | none                      | conchoidal | flint                          |
| 22  | sod. borate<br>$\text{Na}_2\text{B}_4\text{O}_7$                | transparent              | no          | no                     | 2.5      | 3 at rt LS                | rough      | halite                         |
| 2   | calcium carbonate<br>$\text{CaCO}_3$                            | white                    | translucent | no                     | 3        | 3 at 75° L<br>11 to faces | rough      | calcite                        |
| 3a  | $\text{CaMg}(\text{PO}_4)_2$                                    | brassish<br>white        | no          | light pink<br>no       | 3        | none                      | conchoidal | dolomite                       |
| 10  | hydrated<br>calcium<br>sulphate                                 | transparent              | translucent | no                     | 2        | good                      | rough      | gypsum                         |
| 21  | hydrated iron<br>$2\text{Fe}_2\text{O}_3 + 3\text{H}_2\text{O}$ | redish<br>brown<br>black | no          | yellowish brown<br>tan | 5.5      | none                      | rough      | limonite                       |
| 21a | $\text{Fe}_2\text{O}_3$                                         | dun red                  | no          | reddish<br>brown       | 4        | none                      | rough      | hematite                       |
| 1   | hydrated<br>aluminum<br>silicate &<br>alumina                   | grayish<br>white         | no          | gray                   | 1        | none                      | rough      | <del>kaolinite</del> kaolinite |
| 3b  | hydrated<br>calcium<br>sulphate                                 | white                    | no          | no                     | 2        | no                        | rough      | alabaster                      |

\* Name compound and principal element, i.e., Iron Sulphide or Calcium Carbonate.

NAME

DIVISION

DATE



# INTRODUCTION TO THE STUDY OF SEDIMENTARY ROCKS

## DEFINITION OF SEDIMENTARY ROCK:

A general term for (1) loose or cemented debris derived from older rocks or (2) organic and solution deposits.

## CLASSIFICATION OF SEDIMENTARY ROCKS:

All sedimentary rocks may be roughly divided into those of mechanical (clastic) and those of chemical origin. The constituents of the sedimentary rocks are derived from the disintegration of older rocks, either igneous, sedimentary, or metamorphic. One of the objects of geology is to teach that throughout geologic time the rocks are constantly being built up and torn down again by natural geologic processes, as described in the prescribed reading. Thus we get cycles of erosion and deposition over and over again, which will continue until the dynamic history of the earth is closed, if it ever be closed! The mechanical or clastic rocks are therefore made up of the disintegrated *fragments* of any pre-existing rocks, and usually may be recognized by the fact that they are stratified, that is, show a banded *structure*, the result of deposition in water or under air. Banded structure in the sedimentary rocks is called *stratification*. True stratification may be shown by difference in size of the constituents which make up the strata, bands, or beds, or by difference in color. The color test is particularly valuable in such fine-grained rocks as shales and shaly limestones, where the constituents are so small that they cannot be distinguished by the naked eye. You must learn to distinguish between the I banded structure (flow structure) in lavas, II the banded structure (foliation) in gneisses and schists, and III the banded structure (stratification or bedding) in sedimentary rocks. This is somewhat difficult in the finer grained rocks. But it must be remembered that the granular igneous rocks and metamorphic rocks are composed of interlocking crystals which have formed from solution, in place, while the fragmental sedimentary rocks are formed from clastic or broken material all of which has been more or less worn or rounded during transportation. Some of the material, as in the case of the breccias, may be quite angular,

but in every case the angularity is never due to the original crystal form; that is why we are apt to designate only the igneous and metamorphic rocks as crystalline. This is really incorrect, because some rocks, such as gypsum and dolomite, have undoubtedly crystallized from *cold* solutions, not magmas, at or near the earth's surface. Hence, although crystalline, they cannot be considered either igneous or metamorphic, but are usually considered sedimentary rocks.

Mechanical or *clastic* (fragmental) sediments may be conveniently classified as to origin. The two principal groups are (A) Continental, (B) Marine. The continental sediments may be further subdivided into (a) sediments deposited in lakes or rivers, (b) glacial sediments, (c) wind-blown sediments. Marine sediments can sometimes be told from continental sediments only by the fossils. No matter what the origin of the sediments, it is customary to classify them according to their structure and texture in the case of the clastic type, mineral or chemical composition becoming a more important classificatory factor in the chemical type. Unfortunately the lithology (mineral content, texture, and structure) may not be a very good criterion as to the origin of a sediment. Thus it is often difficult to tell whether a conglomerate is of marine or continental origin. Glacial conglomerates or tills may be told by the heterogeneous mixture of clay and boulders, but more specifically by the glacial scratches on the boulders themselves. We are not yet sure under just what conditions many thick shale beds were laid down, especially when they contain no fossils. Wind-blown sands may be told from water-laid sands by the rounded form of the sand grains and the peculiar character of their surfaces. In conclusion it should be remembered that most of the types of sedimentary rocks have been formed many times during geologic history, and that we find the same kind of conglomerates, shales, and sandstones in the Pre-Cambrian as are being laid down at the present day. An exception to the above seems to be dolomite, which is relatively more common than limestone in the older formations.

The particular scientific interest of the sedimentary rocks is that in them we find fossils or remains of long extinct organisms. By studying the sediments which enclose the fossils we may hope to determine the environments of past life. Historical Geology deals largely with a discussion of sedimentary rocks, with their faunas, floras, and their deformation, together with igneous

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intrusives and extrusives, into mountain ranges and broad continental uplifts. The mining of coal and oil is intimately associated with the study of the origin and deformation of sediments. In spite of the facts enumerated above, the sedimentary rocks have not been as fully studied as the igneous and metamorphic rocks, so that our present classification is not very satisfactory. *Important:* On page 39 the attempt has been made to classify the crystalline, fine-grained and typically clastic rocks in one table, so as to give some idea as to their origin and evolution. As an aid to specific determinations consult p. 38. You should be warned that the crystalline, sedimentary rocks are really closely related, from the point of view of origin, to the igneous rocks, in that they have crystallized from solution and are not made up of the fragments (clasts) of older rocks. It will be best to consider the rocks on either side of the double line (in the table on p. 39) as representing two more or less distinct groups.

## INSTRUCTOR'S REMARKS

MACROSCOPIC DETERMINATION OF CLASTIC SEDIMENTARY ROCKS

I. TEXTURE. Absolute and relative size of clastic constituents (clasts).<sup>1</sup>

A. *Even-grained*.

- 1) Indistinguishable = colloidal. (below 1/256 mm.)
- 2) Very fine = dust. (1/8-1/256 mm.)
- 3) Fine = sand. (1-1/8 mm.)
- 4) Medium = grit. (2-3 mm.)
- 5) Coarse = pebbles (rounded) or anguclasts (angular). (3-64 mm.)
- 6) Very coarse = boulders (rounded) or blocks (angular). (65-256 mm.)

B. *Uneven-grained (Phenoclastic)*.

- 1) Conglomeratic. The relatively larger clasts (phenoclasts) are called pebbles (spheroclasts) and are surrounded by a *matrix* of clay, grit, or sand, the whole being bound or held together (lithified = turned to stone) by a cement. The common cements are a) quartz, b) clay, c) hematite (red), d) ferrous iron compounds (green), e) limonite (red to brown), f) calcite or dolomite.
- 2) Brecciated. The relatively larger clasts (phenoclasts) are called anguclasts (angular-clast) and are surrounded by a *matrix* of clay, grit, or sand, the whole being bound or held together by any of the cements mentioned above.

II. STRUCTURE. Arrangement of the clastic constituents (clasts).

A. *Scattered or mixed, no apparent stratification*.<sup>2</sup>

B. *Banded. Bedding or stratification*.

- 1) Regular bedding.
- 2) Cross bedding.
- 3) Wavy and concentric.

III. MINERAL COMPOSITION. Color.

<sup>1</sup> Sedimentary fragments of any size or shape.

<sup>2</sup> Hand specimens are sometimes too small to show bedding. Also loose or unconsolidated materials lose their bedding when brought into the laboratory.

size of grains →

## CLASSIFICATION OF COMMON SEDIMENTARY ROCKS

| ESSENTIAL<br>CHEMICAL OR<br>MINERAL<br>COMPOSITION                                          | Visibly<br>crystalline                       | Indeterminate<br>Colloidal or<br>cryptocrystalline or<br>cryptoclastic | Clastic or<br>"concretionary" | size of grains                                                    |                                                 |
|---------------------------------------------------------------------------------------------|----------------------------------------------|------------------------------------------------------------------------|-------------------------------|-------------------------------------------------------------------|-------------------------------------------------|
|                                                                                             |                                              |                                                                        |                               | 4                                                                 | 5                                               |
|                                                                                             |                                              |                                                                        |                               | Pebbles (Spheroclasts)                                            | Angulasts                                       |
| (SEE SECTIONS ON IGNEOUS<br>AND SEDIMENTARY MINER-<br>ALS FOR DISTINGUISHING<br>CHARACTERS) | Precipitates<br>from<br>aqueous<br>solutions | Very fine grained                                                      | Fine to medium grained        | Coarse to very coarse grained (Phenoclastic)                      |                                                 |
|                                                                                             |                                              |                                                                        | UNCONSOLIDATED                | - un cemented                                                     |                                                 |
|                                                                                             |                                              | CLAY, MUD, LOESS                                                       | SANDS AND GRITS <sup>1</sup>  | GRAVELS AND BOULDER DEPOSITS                                      |                                                 |
|                                                                                             |                                              |                                                                        | CONSOLIDATED                  | - cemented                                                        |                                                 |
| KAOLINITE                                                                                   | ×                                            | SHALE AND ARGILLITE                                                    | ×                             | ×                                                                 | ×                                               |
| CALCITE (CaCO <sub>3</sub> )                                                                | STALACTITES<br>STALAGMITES<br>LIMESTONE      | LIMESTONES                                                             | OOLITIC LIMESTONES            | LIMESTONE<br>CONGLOMERATE,<br>COQUINA                             | LIMESTONE<br>BRECCIA,<br>COQUINA                |
| KAOLINITE AND<br>CALCITE                                                                    | ×                                            | CALCAREOUS SHALES,<br>ARGILLACEOUS<br>LIMESTONES                       | ×                             | ×                                                                 | ×                                               |
| DOLOMITE<br>(CaCO <sub>3</sub> · MgCO <sub>3</sub> )                                        | ?                                            | DOLOMITE                                                               | OOLITIC DOLOMITE              | DOLOMITE<br>CONGLOMERATE                                          | DOLOMITE<br>BRECCIA                             |
| QUARTZ OR SILICA<br>(SiO <sub>2</sub> )                                                     | ?                                            | CHERT, FLINT, ETC.                                                     | SANDSTONES <sup>1</sup>       | CONGLOMERATES <sup>2</sup>                                        | ?                                               |
| GYP-SUM (CaSO <sub>4</sub> )                                                                | SELENITE                                     | ALABASTER                                                              | ?                             | ×                                                                 | ×                                               |
| HALITE (NaCl)                                                                               | ROCK SALT                                    | ×                                                                      | ×                             | ×                                                                 | ×                                               |
| HEMATITE (Fe <sub>2</sub> O <sub>3</sub> )                                                  | ×                                            | DENSE HEMATITE                                                         | OOLITIC HEMATITE              | ×                                                                 | ×                                               |
| LEMONITE<br>(Fe <sub>2</sub> O <sub>3</sub> · x H <sub>2</sub> O)                           | ×                                            | BOG IRON ORE                                                           | ×                             | ×                                                                 | ×                                               |
| GLOMERATES OR<br>MIXTURES OF SEVERAL<br>SPECIES OF ROCKS                                    | ×                                            | ×                                                                      | ×                             | CONGLOMERATES <sup>2</sup><br>(named according to<br>composition) | BRECCIAS<br>(named according to<br>composition) |

<sup>1</sup>"Sand" and "Sandstone" are usually composed largely of quartz grains (clasts), but the term sand implies size of grain rather than mineral composition.

<sup>2</sup>Conglomerates in which the pebbles are all monomineralic or even composed of one kind of rock are rather rare. Most Conglomerates are heterogeneous mineralogical and lithological mixtures. (1), (2). The common cements in Sandstones and Conglomerates, are CaCO<sub>3</sub>, SiO<sub>2</sub>, clay and the iron oxides. The common matrices are clay, sand or grit (siliceous or calcareous).

x No representative.



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### ESSENTIAL CHARACTERISTICS OF COMMON SEDIMENTARY ROCKS

#### CARBONATE ROCKS:

The principal carbonate rocks are limestone and dolomite. Each is easily distinguished by the chemical reaction (HCl acid test) for the minerals calcite and dolomite, respectively. The different types of carbonate rocks together with their specific characters are listed below.

##### LIMESTONE:

A general term for any coarse to fine-grained rock which is composed principally of calcium carbonate ( $\text{CaCO}_3$ ). Limestones may be of almost any color but usually range from white to black (carbonaceous limestones). The latter may be confused with black shales or argillites (from which they may be distinguished by the acid test) and with the fine-grained basalts (from which they may be distinguished by their relative "softness"). The light colored varieties of limestone are more apt to be visibly granular or crystalline. Coarse grained, crystalline limestones are difficult to distinguish from marble unless you know the "field relationships."

##### DOLOMITE:

Since you will be unable to determine the physical differences between the minerals calcite and dolomite we may say that the rock dolomite is similar in all respects to limestone save for the "acid test," which must be very carefully applied.

##### OÖLITIC LIMESTONES AND DOLOMITES:

Are distinguished by the fact that they are made of small carbonate concretions about the size and shape of fish-roe. They are most easily distinguished from typical sandstones (siliceous) by the acid test. It is difficult to distinguish the difference between oolites and rounded sand grains (wind blown sand) without the aid of the microscope.

##### COQUINA AND SHELL LIMESTONE:

Calcareous rocks which are either entirely composed of shells or bits of shells (coquina) or contain abundant fossils (Shell Limestone). Shell limestone may be thought of as an ancient coquina. As both types have a phenoclastic texture they have

been placed in the table under the conglomerates and breccias, according to whether or not their phenoclasts (in this case, shells) are rounded or angular.

#### STALACTITES AND STALAGMITES:

"Depending" or "uprising," columnar, icicle-like deposits, generally of calcite, formed on the roof or floor of a cave by the drip of mineral solution. Easily distinguished by shape, mode of occurrence, and "acid test." Visibly crystalline.

#### ARGILLACEOUS ROCKS:

Fine-grained, relatively soft rocks, all colors. Some types may be easily confused with the fine-grained basaltic and felsitic igneous rocks, and fine-grained carbonate rocks. The argillaceous rocks range in chemical composition from pure clays (Kaolinite) to calcareous clays or siliceous clays. Pure clay may be told by its peculiar odor, but this is not a very safe criterion. If the rock is (1) easily scratched with a knife, (2) does not react with acid (HCl), (3) is not visibly crystalline, (4) has an argillaceous odor, then it is probably a *shale* or an *argillite*.

#### SHALE:

A fine-grained, friable rock of various colors. Soft, does not react with acid (HCl), and has an argillaceous odor. Calcareous shales grade into shaly limestones. There is probably no clear line of separation.

#### ARGILLITE:

A dense, fine-grained rock of various colors (usually white, gray, or red), composed of minute grains of both clay and quartz. Harder than shale and easily confused with felsite except that it scratches more easily with a knife. Argillites grade into argillaceous limestones. There is probably no clear line of separation.

#### SILICEOUS ROCKS:

Siliceous rocks range both in texture and chemical composition from fine-grained argillites, through medium-grained sandstones to quartz conglomerates. Both the sandstones and the conglomerates may have matrices or cements of other substances. In the coarser types care must be taken to distinguish the character and composition of both the clasts and the cement.

#### SULPHATES, CHLORIDES, AND IRON OXIDES:

Apply mineral tests.

## GEOLOGY MANUAL

### LABORATORY EXERCISES ON SEDIMENTARY ROCKS

EXERCISE A. Study the named rocks in the trays, using the "Introduction to the Study of Sedimentary Rocks" and the "Table of Common Sedimentary Rocks." Be sure that you understand all the terms used in the text. You will be examined later as to your knowledge of these types.

or

EXERCISE B. Identify the numbered (unnamed) rocks in the trays, using the "Introduction to the Study of Sedimentary Rocks" and the "Table of Common Sedimentary Rocks." Enter your conclusions on the laboratory blank, facing p. 40.

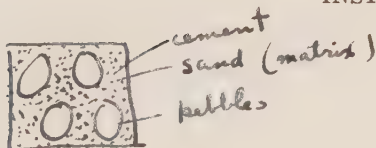
or

EXERCISE C. Describe and name the sedimentary rocks in your trays without reference to your laboratory manual. Enter all your conclusions on the laboratory blank, facing p. 40.

### TEST QUESTIONS

1. What is a sedimentary rock?
2. How would you tell a sedimentary from an igneous rock?
3. Discuss the method of sedimentary rock classification.
4. How would you tell *stratification* from *flow*?
5. How would you distinguish between the following fine-grained, *dark colored* rocks:  
a) carbonaceous limestone, b) dark dolomite, c) carbonaceous shale, d) basalt, e) black chert, f) dark argillite, g) obsidian.
6. How would you distinguish between the following fine-grained, *light colored* rocks:  
a) felsite, b) light colored limestone, c) light colored dolomite, d) light colored argillite, e) light colored chert, f) oolitic limestone, g) white sandstone.
7. Define the following terms: a) clast, b) phenoclast, c) structure, d) texture, e) matrix, f) colloid, g) dust, h) sand, i) grit, j) pebble, k) block, l) boulder, m) striae, n) oolite, o) lithification, p) anguclast, q) spheroclast.

### INSTRUCTOR'S REMARKS



# LABORATORY BLANK

## SEDIMENTARY ROCKS

| NO. | TEXTURE, SIZE AND SHAPE OF CLASTS <sup>1</sup> | STRUCTURE | IF CONGLOMERATE OR BRECCIA |                            | CEMENT            | COMPOSITION                 | NAME                                  |
|-----|------------------------------------------------|-----------|----------------------------|----------------------------|-------------------|-----------------------------|---------------------------------------|
|     |                                                |           | PHENOCLASTS                | MATRIX                     |                   |                             |                                       |
| 29  | even intermediate colored                      | scattered |                            |                            | clay              | kaolinite silica            | argillite                             |
| 8   | even colloidal                                 | "         |                            |                            | clay              | kaolinite calcium carbonate | calcareous shale                      |
| 7   | even colloidal                                 | "         |                            |                            | clay              | kaolinite                   | clay shale                            |
| 24  | "                                              | "         |                            |                            | lime              | calcium carbonate kaolinite | argillaceous limestone                |
| B21 | even fine                                      | "         |                            |                            | SiO <sub>2</sub>  | silica                      | red sandstone                         |
| 627 | uneven                                         | "         | shells (lime)              | calcium carbonate + silica |                   | calcium carbonate silica    | shell limestone                       |
| 14  | even fine                                      | "         |                            |                            | SiO <sub>2</sub>  | silica (kaolinite)          | sandstone with argillaceous character |
|     | even fine                                      | "         |                            |                            | SiO <sub>2</sub>  | silica                      | white sandstone                       |
|     | uneven                                         | "         |                            |                            | SiO <sub>2</sub>  | silica                      | silicified sand                       |
|     | fairly even                                    | "         |                            |                            | CaCO <sub>3</sub> | calcium carbonate silica    | cherty limestone                      |

<sup>1</sup>Character of the surface of the constituents is important in the case of AEOLIAN and GLACIAL sediments.

uneven " argillaceous, silicea CaCO<sub>3</sub> " " CaCO<sub>3</sub> SiO<sub>2</sub> limestone conglomerate

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## ESSENTIAL CHARACTERISTICS OF COMMON MINERALS IN METAMORPHIC ROCKS

For method of studying the metamorphic minerals, see "Introduction to the Study of Minerals," p. 4. For minerals common in both igneous, sedimentary, and metamorphic rocks (quartz, micas, pyriboles, feldspars, carbonates), see previous exercises.

**CHLORITE:** ( $\text{H}_3\text{Mg}_5\text{Al}_2\text{Si}_8\text{O}_{20}$ )

Magnesium, iron, aluminium silicate. Occurs as crystals with a roughly six-sided outline, but usually as scaly flakes or masses. Chlorite is similar to mica in the shape of the crystals and excellent basal cleavage, but differs from mica in that although the scales or plates are flexible they are inelastic. Hardness, 2; color, green.

**SERPENTINE:** (See rock specimen) ( $\text{H}_4\text{Mg}_3\text{Si}_2\text{O}_9$ )

Magnesium silicate. Occurs in compact, granular or fibrous masses. Luster greasy, and hand specimen has a soapy feeling. The fibrous variety, chrysotile, is used as asbestos. Serpentine is also used for interior decoration.

**TALC:** (*Plate II, fig. 2*) ( $\text{H}_2\text{Mg}_3(\text{SiO}_3)_4$ )

Occurs in scales, fibers, or compact masses. One of the softest minerals, and easily scratched by the flesh. Greasy feel. When compact, the variety is called *soapstone*, and is much used for sinks, etc. The pure varieties are ground fine and used as fillers in paints, papers, roofing materials, etc. Hardness, 1; color, white, grey or green.

**GARNET** ( $\text{R}''_3\text{R}'''_2$ ) ( $\text{SiO}_4$ )<sub>3</sub>)

A series of interesting double silicates which also occur in the igneous rocks. The crystal form is usually a remarkably symmetrical polyhedron of 12, 24, or 36 sides. *Pyrope* is a beautiful deep red in color and is much prized as a precious stone. Garnet has no cleavage, and its hardness is between 7 and 8. The common garnets are usually dark red or brown. Garnet is most apt to occur in schists.

**EPIDOTE:** ( $\text{H}\text{Ca}_2(\text{Al}, \text{Fe})_3\text{Si}_3\text{O}_{13}$ )

A complex calcium, iron, aluminium silicate which occurs

either in grains or columnar masses. Color, a distinctive pistachio or yellow-green. Vitreous luster. Hardness, 6.5. Epidote is easily recognized by its hardness and peculiar green color.

(OTTRELITE:  $(\text{H}^2(\text{Fe}^2, \text{Mn}) \text{Al}^2\text{Si}^2\text{O}^9)$ )

An iron, magnesium-rich aluminum silicate. Important constituent of certain schists, especially those with slaty cleavage. Color, black. Hardness, 6-7. May be mistaken for biotite.

(STAUROLITE:  $(\text{HFeAl}_5\text{Si}_2\text{O}_{13})$ )

An iron aluminium silicate of variable composition. An important constituent of certain schists. Easily recognized by its well-formed crystals (metacrysts) which are either "roof-shaped" or twinned to form "crosses." "From the seventeenth century on, it has been used as a baptismal stone, and worn as a charm, legends stating that it fell from the heavens. . . . When the fairies heard of the crucifixion of Christ, they wept, and their tears falling crystallized in the form of crosses. . . ." (Loomis.)

NOTE: For a discussion of the origin of metamorphic minerals and rocks, see your lecture notes and textbook.

## INSTRUCTOR'S REMARKS

Flat rock is a slate or phyllite  
~~phylite~~

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## ESSENTIAL MINERALS IN METAMORPHIC ROCKS

| NO. | FORM         | COMPOSITION*                | COLOR and LUSTER   | HARDNESS | CLEAVAGE   | FRACTURE | NAME       | OTHER OBSERVATIONS |
|-----|--------------|-----------------------------|--------------------|----------|------------|----------|------------|--------------------|
| 1   | scaly mass   | magnesium aluminum silicate | green dark brown   | 2        | good       | rough    | chlorite   |                    |
|     | compact mass | mg. silicate                | green greasy       | 3        | no         | rough    | serpentine |                    |
|     | scaly mass   | mg. silicate                | light green bluish | 1        | op. interg | rough    | talc       |                    |
|     | nodul.       | silicate                    | greenish brown     | 1        | no         | rough    | garnet     |                    |
|     | mass         | (Ca, Fe, Al) silicate       | postachio dull     | 6.5      | no         | rough    | epidote    |                    |
|     |              |                             |                    |          |            |          |            |                    |
|     |              |                             |                    |          |            |          |            |                    |
|     |              |                             |                    |          |            |          |            |                    |
|     |              |                             |                    |          |            |          |            |                    |
|     |              |                             |                    |          |            |          |            |                    |

\* Name compound and principal element, i.e., chlorite, magnesium aluminum silicate.

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### LABORATORY EXERCISE ON METAMORPHIC ROCK MINERALS

EXERCISE A. Study the named minerals in the trays, using the "Introduction to the Study of Minerals" and the "Essential Characteristics of Common Minerals in Metamorphic Rocks." You will be examined later as to your knowledge of these minerals.

*or*  
EXERCISE B. Identify the numbered (unnamed) minerals in the trays, using the "Introduction to the Study of Minerals" and the "Essential Characteristics of Common Minerals in Metamorphic Rocks." Enter your conclusions on the laboratory blank, facing p. 44.

*or*  
EXERCISE C. Describe<sup>1</sup> and name the minerals in your trays without reference to the text. Enter your conclusions on the laboratory blank, facing p. 44.

<sup>1</sup> This test may be made to include all the minerals previously studied.

### TEST QUESTIONS

1. What is a metamorphic mineral?
2. What minerals are found only in metamorphic rocks? - *chlorite, serp., talc, garnet, epidote, staurolite*
3. Review questions on igneous, sedimentary and metamorphic minerals.

### INSTRUCTOR'S REMARKS



# INTRODUCTION TO THE STUDY OF METAMORPHIC ROCKS

## DEFINITION OF METAMORPHIC ROCK:

A rock derived from a pre-existing rock by mineralogical, textural and structural changes within the original mass.

## CLASSIFICATION OF METAMORPHIC ROCKS

Metamorphism means change. Thus the term, in its widest sense, may be applied to any rock, igneous or sedimentary, which has undergone any kind of change. It might also be applied to the consolidation or lithification of sediments. In geology, however, the term is usually applied to the transformation of either sedimentary or igneous rocks into a crystallized (usually recrystallized) and usually banded rock, such as a gneiss or schist. This type of banding we call foliation or schistosity, and you must learn to differentiate it from the other types of banding which are characteristic of the igneous and sedimentary rocks. Sometimes the metamorphism is largely physical or structural, although it is quite possible that minute chemical changes have taken place. *Slaty cleavage* and certain types of schistosity are produced in this way. Metamorphism is usually accompanied by chemical changes and recrystallization. The subject of the metamorphic rocks is one of the most difficult in geology. The classification of the metamorphic rocks is therefore far from simple, and the student must be trained in physical chemistry, mineralogy, and petrology before he can hope to accomplish much in the study of the metamorphic rocks. It is often difficult to determine whether a gneiss is of sedimentary or igneous origin, and a classification of natural objects which is not founded on their genesis (origin and evolution) is not of much philosophical value. The metamorphism of the igneous rocks is usually carried on deep beneath the earth's surface, very slowly, under considerable heat and *differential* pressures. From this brief discussion above it will be seen that we can roughly classify the metamorphic rocks as to (A) origin, (B) structure, and (C) mineral composition. Under (A) we have: (1) metamorphosed igneous rocks, (2) metamorphosed sedimentary rocks, and (3) metamorphic rocks resulting from the contact of sedimentary

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rocks with igneous intrusions. These are usually spoken of as being due to *contact metamorphism* and it is here that we are apt to find valuable ore deposits. The great bulk of the gneisses and schists are due to *regional metamorphism* (deep burial and earth movements). Under (B) we may separate our metamorphic rocks into those which are: (1) foliated, (2) non-foliated, or massive, and (3) "cleaved," or those which show slaty cleavage. Under (1) we have the gneisses and schists, under (2) the quartzites and marbles, and under (3), the slates. Under (C) we classify our metamorphic rocks as to their mineral composition; i.e., quartzite, soapstone, etc. Thus, once a rock has been determined as being metamorphic, it is apt to be named according to its mineral composition; i.e., granite, gneiss, quartzite, etc. For a more detailed account of the processes of metamorphism, see your lecture notes and text.

## INSTRUCTOR'S REMARKS

A. origin

1. metamorphosed igneous rocks
2. " " sedimentary "
3. metamorphic rocks resulting from contact of sed. rocks with igneous intrusives. (contact metamorphic)

### B. structure

1. foliated  
gneisses  
Schiists
2. massive  
quartzites, marbles
3. cleaved - slaty cleavage  
the slates

c. mineral composition

MACROSCOPIC DETERMINATION OF THE METAMORPHIC ROCKS

I. TEXTURE. Absolute or relative size of mineral grains

A. *Even-grained*.

- 1) Fine (indistinguishable).
- 2) Medium.
- 3) Coarse.

B. *Uneven-grained*.

- 1) Porphyritic (pseudo-porphyritic). The large crystals are called phenocrysts (metacrysts),<sup>1</sup> meaning "show-crystals," and are surrounded by a matrix of smaller grains or crystals.
- 2) Slaty-porphyritic. The phenocrysts (metacrysts) are surrounded by a matrix of very fine or invisible grains.

II. STRUCTURE. Arrangement of constituents.

A. *Non-foliated*. Metamorphic rocks which are the result of recrystallization without apparent banding or foliation.

B. *Foliated*. Metamorphic rocks which have been recrystallized in such a way as to produce a foliated rock, the separate bands or laminae being distinguished by the size or character (or both) of the constituents. The foliation may or may not be parallel to the bedding.

- 1) Coarsely foliated = gneissic.
- 2) Finely foliated = schistose.

C. "*Cleaved*." Metamorphic rocks of fine texture, such as the slates and phyllites, in which the parallelism of the microscopic constituents is shown by well defined "cleavage." This type of "cleavage" is not to be confused with the cleavage developed in minerals, and may or may not be parallel to the bedding.

<sup>1</sup> The term *phenocryst* is used instead of *metacryst* because the former is directly descriptive of the relative size of the crystals, while the latter is not.

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## TABLE OF COMMON METAMORPHIC ROCKS

| MODE OF OCCURRENCE<br>(read across)      |                                                                                                                                                | Result of either regional or contact metamorphism or injection. Altered <u>sedimentary</u> or igneous rocks.                                         |                                                                                                                                                  |                                                                 |
|------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------|
| (TEXTURE <sup>1</sup> )<br>(read across) |                                                                                                                                                | Absolute size of crystals varies from microcrystalline to coarse grain. <u>Some</u> of the metamorphic rocks especially the schists are porphyritic. |                                                                                                                                                  |                                                                 |
| STRUCTURE<br>(read across)               |                                                                                                                                                | FOLIATED                                                                                                                                             | MASSIVE                                                                                                                                          | CLEAVED                                                         |
| Essential Minerals                       | Other Minerals                                                                                                                                 | ROCK NAME                                                                                                                                            |                                                                                                                                                  |                                                                 |
| feldspar                                 | quartz<br>mica<br>sericite<br>hornblende                                                                                                       | Coarsely foliated GNEISS and PORPHYRITIC GNEISS. INJECTION GNEISS.                                                                                   | <i>Important</i><br>May appear non-foliated or massive in a plane at right angles to the plane of foliation or in the plane of foliation itself. | PHYLLITE -<br>and<br>PORPHYRITIC PHYLLITE<br><i>Shiny - X =</i> |
|                                          | quartz<br>muscovite<br>biotite<br>hornblende ( <i>very foliated</i> )<br>chlorite<br>talc<br><br>ottrelite<br>staurolite<br>garnet<br>feldspar | Finely foliated SCHIST and PORPHYRITIC SCHIST. Each species is named after the predominate or noticeable mineral                                     |                                                                                                                                                  |                                                                 |
| quartz                                   |                                                                                                                                                | QUARTZITE                                                                                                                                            | QUARTZITE                                                                                                                                        |                                                                 |
| serpentine                               | talc                                                                                                                                           | SERPENTINE                                                                                                                                           | SERPENTINE                                                                                                                                       |                                                                 |
| talc                                     | chlorite<br>dolomite                                                                                                                           | SOAPSTONE                                                                                                                                            | SOAPSTONE                                                                                                                                        |                                                                 |
| dolomite                                 | iron min.<br>graphite                                                                                                                          | MARBLE<br><i>scratchable</i>                                                                                                                         | MARBLE                                                                                                                                           |                                                                 |
| calcite                                  | tremolite<br>graphite (e)                                                                                                                      | MARBLE<br><i>reacts to HCl</i>                                                                                                                       | MARBLE                                                                                                                                           |                                                                 |
| calcite<br>serpentine                    | dolomite                                                                                                                                       | OPHICALCITE<br><i>marble bearing serpentine</i>                                                                                                      | OPHICALCITE                                                                                                                                      |                                                                 |
| INVISIBLE                                |                                                                                                                                                |                                                                                                                                                      |                                                                                                                                                  |                                                                 |
| quartz<br>feldspar<br>sericite<br>etc.   | carbonaceous matter<br>pyrite<br>hematite                                                                                                      |                                                                                                                                                      |                                                                                                                                                  |                                                                 |
|                                          |                                                                                                                                                | SLATE and PORPHYRITIC SLATE                                                                                                                          |                                                                                                                                                  |                                                                 |

NOTE: The term *porphyritic* is used in this table in the same sense as in the table of igneous rocks.

<sup>1</sup>Texture is not as important a criterion in the metamorphic rocks as *Structure and Composition*.

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### LABORATORY EXERCISES ON METAMORPHIC ROCKS

EXERCISE A. Study the named rocks in the trays, using the "Introduction to the Study of Metamorphic Rocks," the "Macroscopic Determination of the Metamorphic Rocks," and the "Table of Common Metamorphic Rocks." Be sure that you understand all of the terms used in the text. You will be examined later as to your knowledge of the metamorphic rocks.

or  
EXERCISE B. Identify the numbered (unnamed) rocks in the trays, using the "Introduction to the Study of Metamorphic Rocks," the "Macroscopic Determination of the Metamorphic Rocks," and the "Table of Common Metamorphic Rocks." Enter your conclusions on the laboratory blank, facing p. 50.

or  
EXERCISE C. Describe and name the metamorphic rocks in your trays (without reference to your laboratory manual). Enter all your conclusions on the laboratory blank, facing p. 50.

or  
EXERCISE D.<sup>1</sup> Describe and name the different rocks in your trays without reference to your laboratory manual. Enter all your conclusions on the laboratory blank, facing p. 50.  
(test on all rocks)

<sup>1</sup> It may prove best to examine the student on his knowledge of all the minerals and rocks (igneous, sedimentary, and metamorphic) at the close of his mineral and rock studies.

### TEST QUESTIONS

1. What is a metamorphic rock?
2. How would you differentiate between bedding or stratification and foliation?
3. Discuss the method of classifying the metamorphic rocks.
4. How would you distinguish a slate or phyllite from a shale?
5. Define the following terms: a) metamorphism, b) regional metamorphism, c) contact metamorphism, d) schistosity, e) foliation, f) texture, g) structure, h) phenocryst, i) metacryst, j) slaty cleavage.

### INSTRUCTOR'S REMARKS

A flat rock is either slate or phyllite



# LABORATORY BLANK

## COMMON METAMORPHIC ROCKS

| NO. | TEXTURE                   | STRUCTURE              | MINERAL COMPOSITION                 | NAME                         | OTHER OBSERVATIONS |
|-----|---------------------------|------------------------|-------------------------------------|------------------------------|--------------------|
|     | <del>even</del><br>medium | foliated<br>gneiss     | quartz - hornblende                 | granite schist               |                    |
|     | even<br>fine              | foliation<br>schist    | take schist                         | hornblende-take schist       |                    |
|     | even                      | unfoliated             | hornblende                          | hornblende schist            |                    |
|     | fine                      | schist                 |                                     |                              |                    |
|     | even                      | cleaved                | (marble -<br>quartz, calcite, etc.) | slate                        |                    |
|     | fine                      | non-foliated<br>schist | quartz                              | quartzite                    |                    |
|     | even                      | non-foliated           | CaCO <sub>3</sub>                   | marble                       |                    |
|     | medium                    | cleaved                |                                     | phyllite                     |                    |
|     | even<br>fine              | foliated<br>schist     | quartz - mica                       | schist                       |                    |
|     | even<br>fine              | non-foliated           | Serpentine - marble                 | marble bearing<br>serpentine | ophiolite          |
|     | even<br>medium            | cleaved                | invisible                           | slate                        |                    |
|     | even<br>fine              |                        |                                     |                              |                    |

even  
medium

~~non-foliated~~ schist

gemet crystals

pyllite - with  
crystals

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GENERAL ROCK TEST

| NO. | TEXTURE | STRUCTURE | MINERAL COMPOSITION | NAME | ORIGIN AND DERIVATION* |
|-----|---------|-----------|---------------------|------|------------------------|
|     |         |           |                     |      |                        |
|     |         |           |                     |      |                        |
|     |         |           |                     |      |                        |
|     |         |           |                     |      |                        |
|     |         |           |                     |      |                        |
|     |         |           |                     |      |                        |
|     |         |           |                     |      |                        |
|     |         |           |                     |      |                        |
|     |         |           |                     |      |                        |
|     |         |           |                     |      |                        |

\* Lecture notes and reading.

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## INTRODUCTION TO THE STUDY OF STRUCTURAL GEOLOGY

STRUCTURAL geology concerns itself with the arrangement or rearrangement of the constituents, especially of the outer portion, of the earth. You have already studied the arrangement of the constituents in the rocks themselves. You will now study the arrangement or rearrangement of large masses of rocks, such as are termed *formations*,<sup>1</sup> in the field. Structures may be roughly classified as *primary* or *secondary*. For instance, the stratification or bedding of a sandstone is primary, while the folding of stratified or bedded sandstones into anticlines and synclines is secondary. In a sense, the latter structure is superimposed upon the first, the two being readily distinguishable, except in certain of the metamorphic rocks. Sedimentary rocks are laid down horizontally, or nearly so, and it is by observing and comparing their present with their supposed original position that we are able to work out the structure of a region. In actual practice, this is usually not an easy thing to do without considerable training and experience. All we can hope to do in this course is to introduce you to some of the more striking phenomena. Those who wish to study the subject should take a course in Structural Geology, and should plan to get into the field, under proper guidance, as quickly as possible.

In measuring the rearrangement of formations, that is, in working out the structure of a folded, faulted region, the geologist determines the *strikes* and *dips* of the bedded formations.

### STRIKE:<sup>2</sup>

The direction of a real or imaginary line formed by the intersection of a bed or stratum with a real or imaginary horizontal

<sup>1</sup> A formation may be conveniently defined as: a lithologic unit used for mapping. The determination of what constitutes a lithologic unit must depend more or less upon the special problems of the area which is being surveyed.

<sup>2</sup> It is sometimes easier for the student to understand *dip* and *strike* when defined as follows:

DIP = the maximum angle of inclination of a bedding plane, measured from the horizontal. Quite frequently the true or maximum is difficult to differentiate from the apparent dip, in the field.

STRIKE = the direction of the line of intersection of the plane of the dip with a real or imaginary horizontal plane. The strike tends to be the line of intersection of the beds with the surface of the ground. If the beds are horizontal they have no strike or dip.



plane, such as the surface of the earth, ground water, standing water, or the plane of the horizon (*Plate VII, fig. 3*).

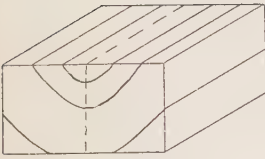
### DIP:

The angle of inclination which the bedding plane makes with a real or imaginary horizontal plane. The angle of the dip must always be measured at right angles to the strike (*Plate VII, fig. 3*).

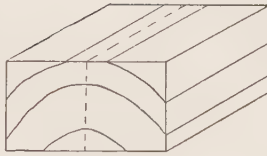
As you have already learned, many of the metamorphic rocks are very ancient igneous or sedimentary rocks which have been altered by regional metamorphism; that is, they have been subjected to deep-seated differential pressures, the result of movements beneath a heavy load of overlying beds. Most of the younger (geologically speaking) sedimentary formations have not been buried deeply enough to undergo true metamorphism, but in many localities have been deformed so as to produce structures which are important, not only from a purely scientific, but also from an economic point of view. Many of our well known mountain ranges (Appalachians, Rocky Mountains, Alps, etc.) are the result of the effect of subaerial erosion upon folded and faulted sedimentary and igneous rocks; and the discovery of oil is largely dependent upon a knowledge of the structures of a region. The student must convince himself that most of the structures which he will study were not produced suddenly but very slowly, with a minimum disturbance at the surface, probably never more than is going on in certain active earthquake areas at the present time. In other words, the uplift (deformation) of any region may be sufficiently slow to cause little or no disturbance, and yet sufficiently rapid (relatively speaking) to counterbalance or even overcome the reduction of altitude brought about by subaerial erosion or down-cutting. For a full discussion of the processes of deformation, you must consult your text and lectures. You will be expected in the laboratory to recognize, define, and interpret some of the simple structures found in the sedimentary rocks in the field. Remember that in this exercise the term *structure* may be used in a larger sense than in the classification of rocks, and you must constantly keep in mind what constitute primary and what secondary structures. The types of secondary structures which you will now study we will call *deformations*. These may be divided, for convenience, into two groups, *folds* and *faults*.

# PLATE VI.

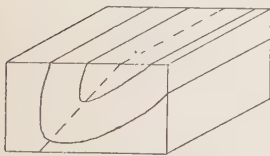
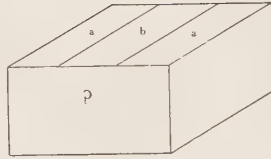
## FOLDS.



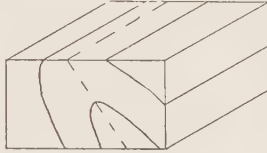
Symmetrical Syncline.



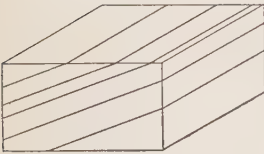
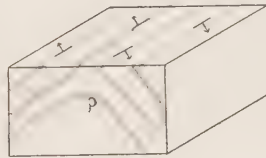
Symmetrical Anticline



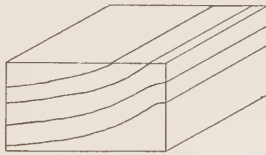
Asymmetrical Syncline



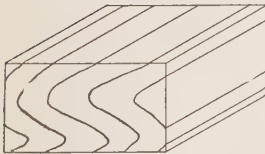
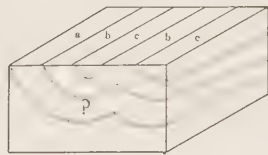
Asymmetrical Anticline



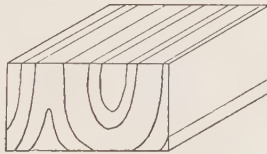
Homocline



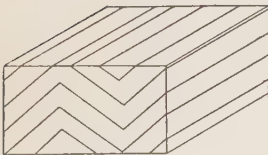
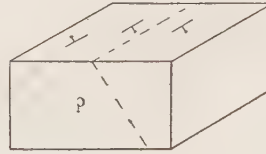
Monocline



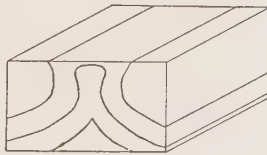
Recumbent Fold



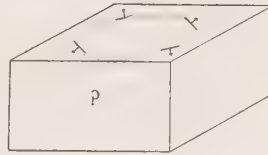
Isoclinal Fold



Chevron Fold

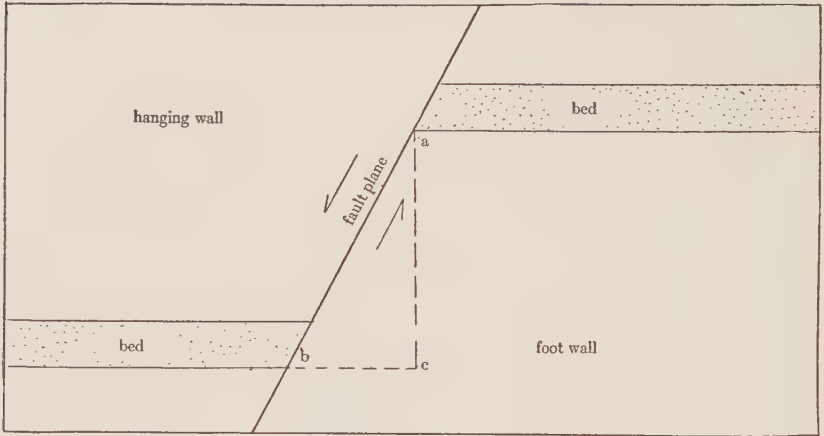


Fan Fold

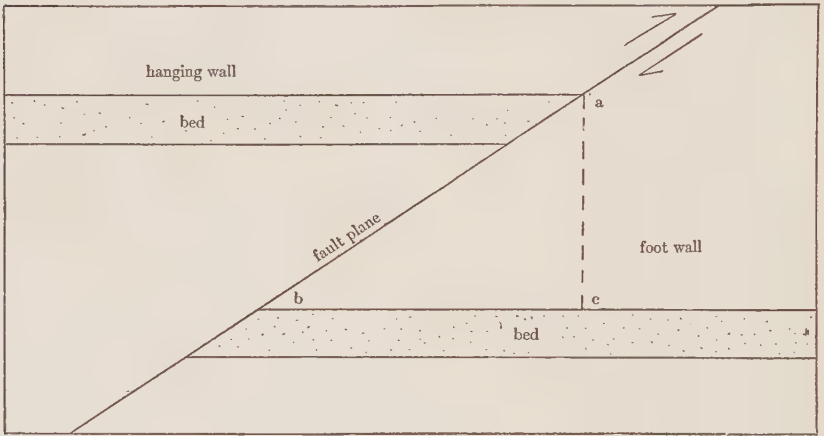


# PLATE VII.

## FAULTS.



Vertical section of a Normal or Gravity Fault.  
abc-dip. bc-heave. ac-throw.



Vertical section of a Reverse or Overthrust Fault  
abc-dip. bc-heave. ac-throw.

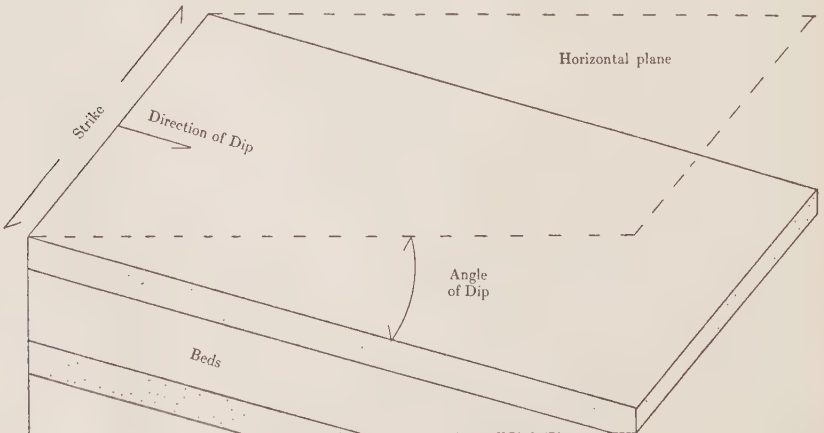


Diagram to illustrate strike and dip.

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### CLASSIFICATION OF FOLDS

(See illustrations, *Plate VI*, p. 53)

- A. *Homocline*: group of strata which all dip in one direction. Never a complete structure.
- B. *Monocline*: simple flexure or step-like bend in otherwise horizontal beds.
- C. *Symmetrical Folds*: Open or closed. Axial plane of bilateral symmetry. 1) anticlines, 2) synclines, 3) chevron folds, 4) fan folds, 5) domes, 6) basins.
- D. *Asymmetrical Folds*: Open or closed. Axial plane unsymmetrical. 1) anticlines, 2) synclines, 3) recumbent folds, 4) fan folds.

### CLASSIFICATION OF FAULTS

(See illustrations, *Plate VII*, p. 54)

#### FAULT DEFINED:

A fault is a fracture on either side of which there has been relative displacement of the once continuous beds.

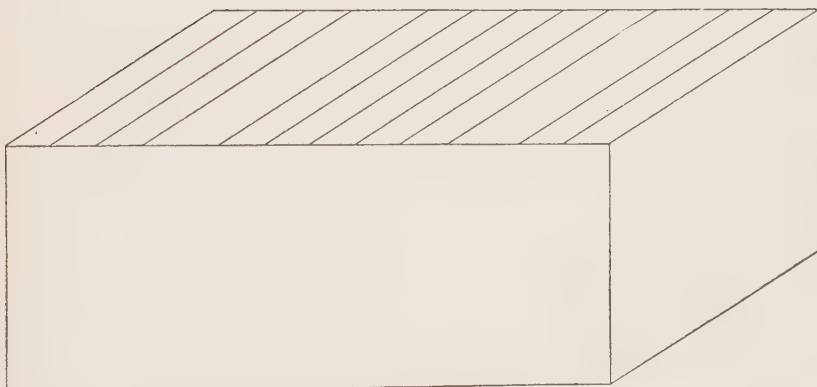
Faulting may be produced by either tension or compression, and, if traced far enough, a fault is found to die out at both ends. Faults may be classified in a number of ways, but we shall only consider examples of the two principal types. For a further discussion of faults, see your text and lecture notes.

- A. *Gravity or Normal Faults*. The result of tension. The fault plane is usually at a high angle.
- B. *Reverse or Overthrust Faults*. The result of compression. Reverse faults may result from extreme folding, or when the stress-strain relationships are such that further lineal shortening cannot be entirely accomplished by increased density, or by folding. The fault plane is usually at a low angle.





## LABORATORY EXERCISE ON FOLDING AND FAULTING



1. Problem in open and symmetrical folds. The relative ages of the beds shown on the horizontal surface of the block diagram to be determined by the instructor. Complete the block diagram so as to show the structure determined by the order of the outcrops (bands).

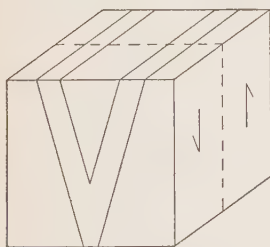


Figure 1.

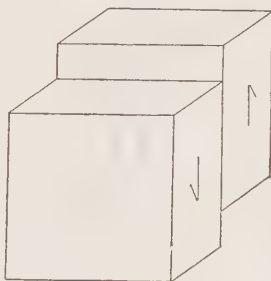


Figure 2.

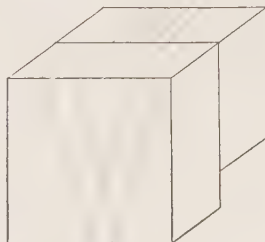


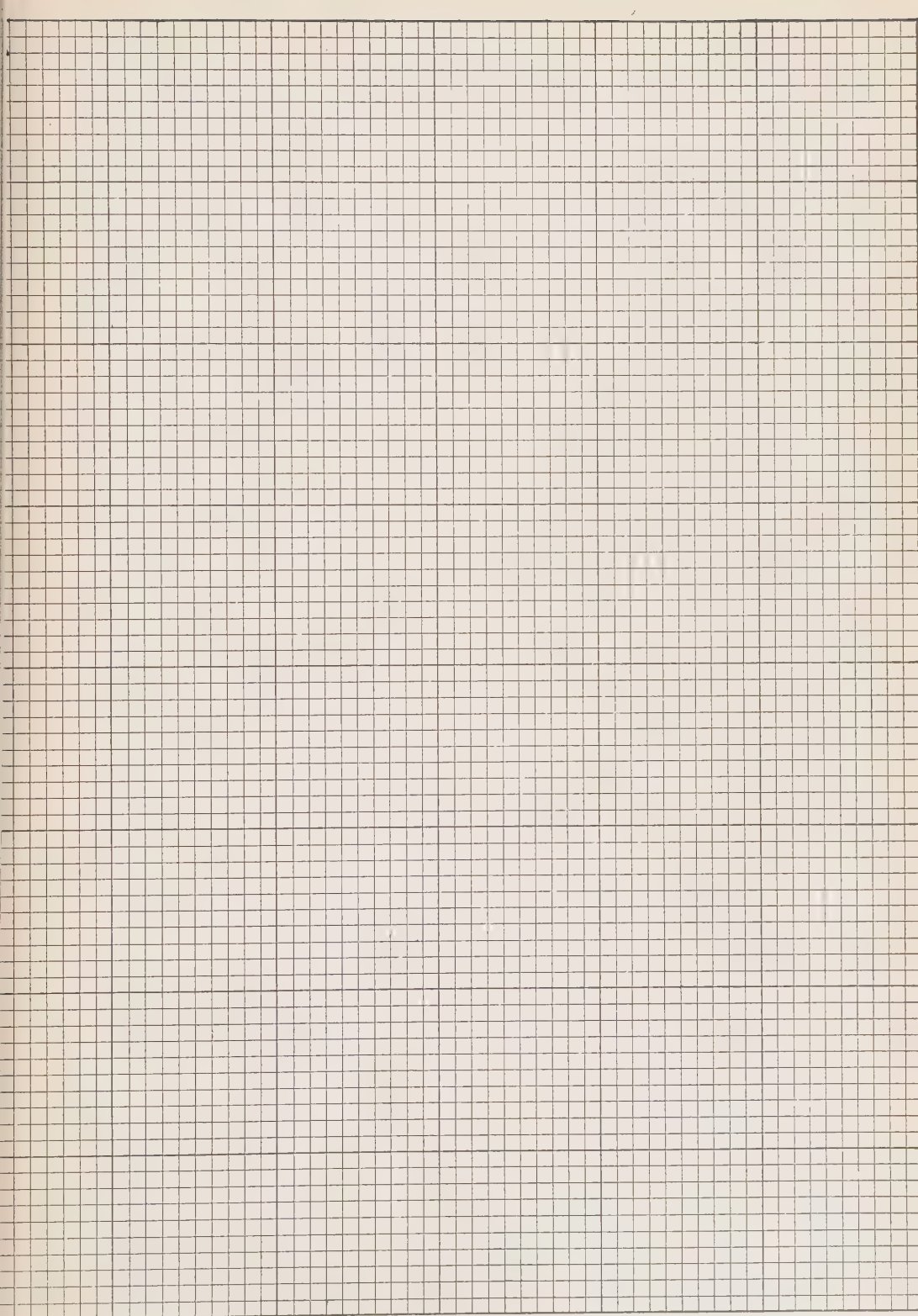
Figure 3.

2. Problem in folding and faulting. Fig. 1 is a block diagram of a syncline the beds of which are to be displaced by a gravity fault as shown. Fig. 2 shows the faulting and the amount of displacement of the two blocks. Fig. 3 shows the erosion of the up-thrown block level with the surface of the down-thrown block. Complete diagrams to show structures.
3. Problem in folding and faulting. Make three block diagrams to illustrate an anticline which has been broken by a normal fault in the same manner as in the preceding exercise.
4. Describe, in detail, the series of events illustrated in problems 1 to 6 on following pages.

NAME

DIVISION

DATE



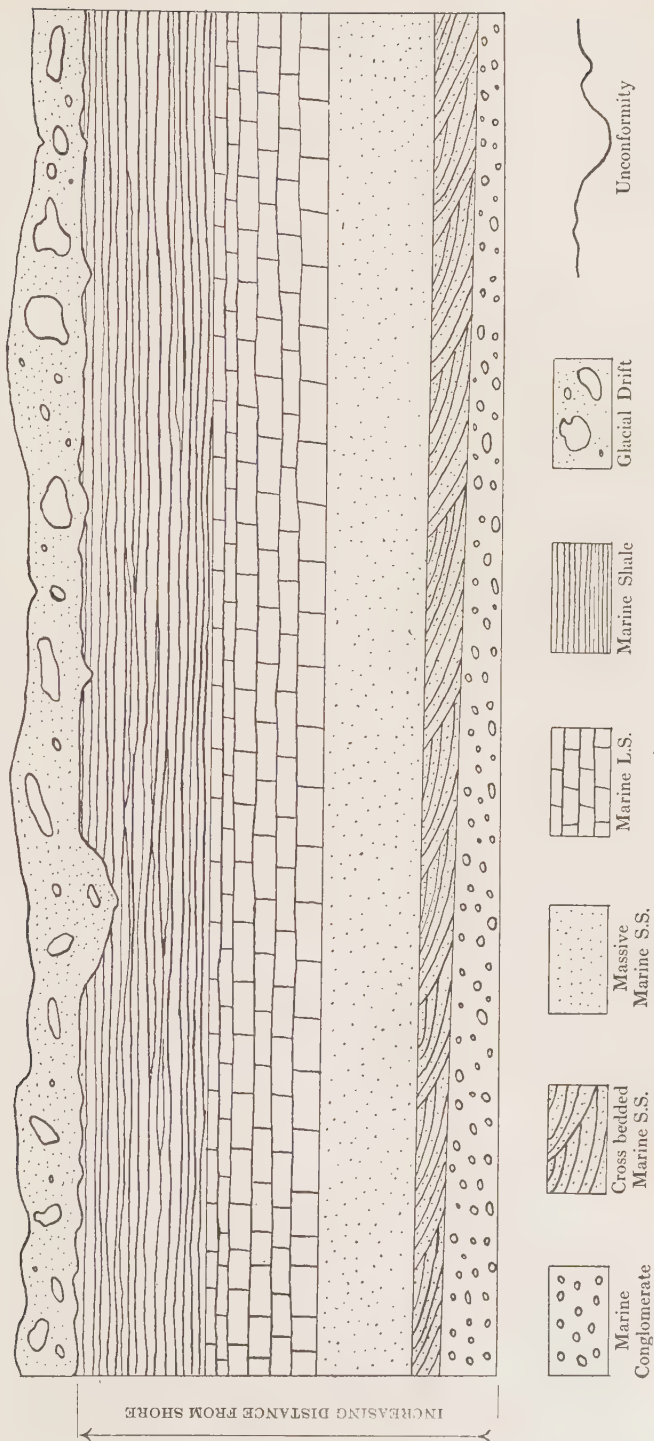
# STRUCTURE

NAME

DIVISION

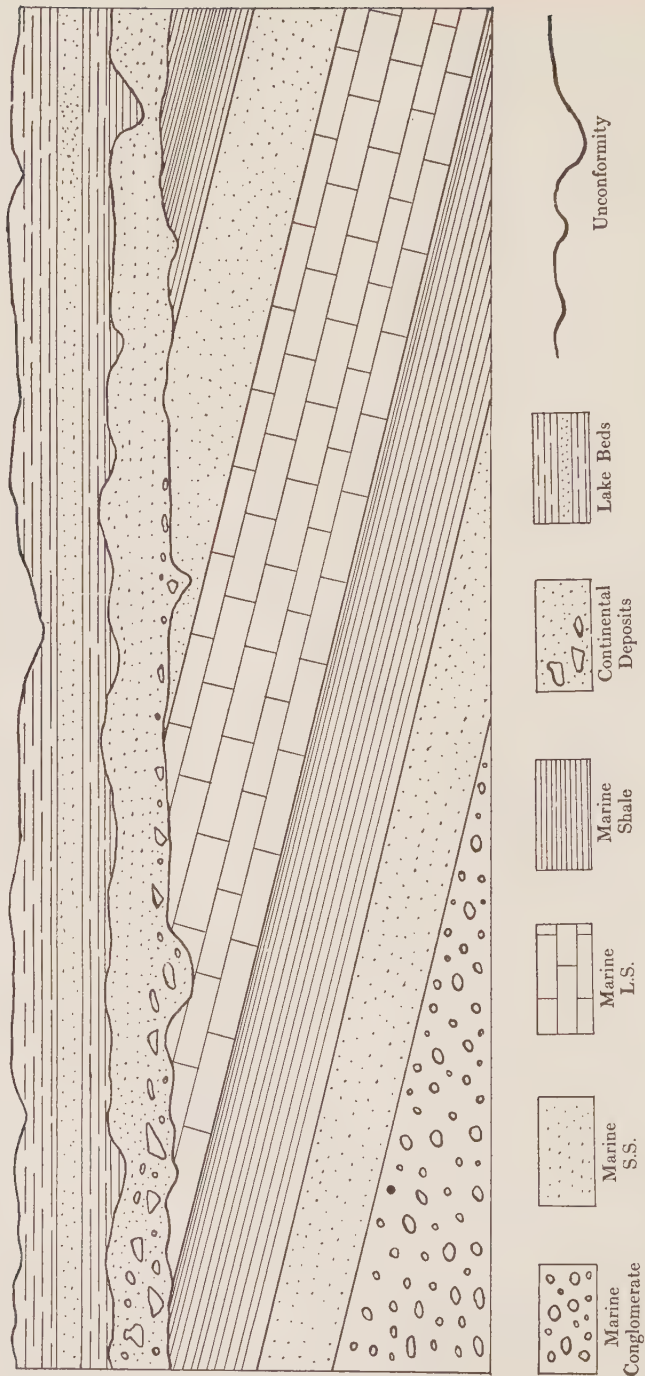
DATE

# PROBLEM 1

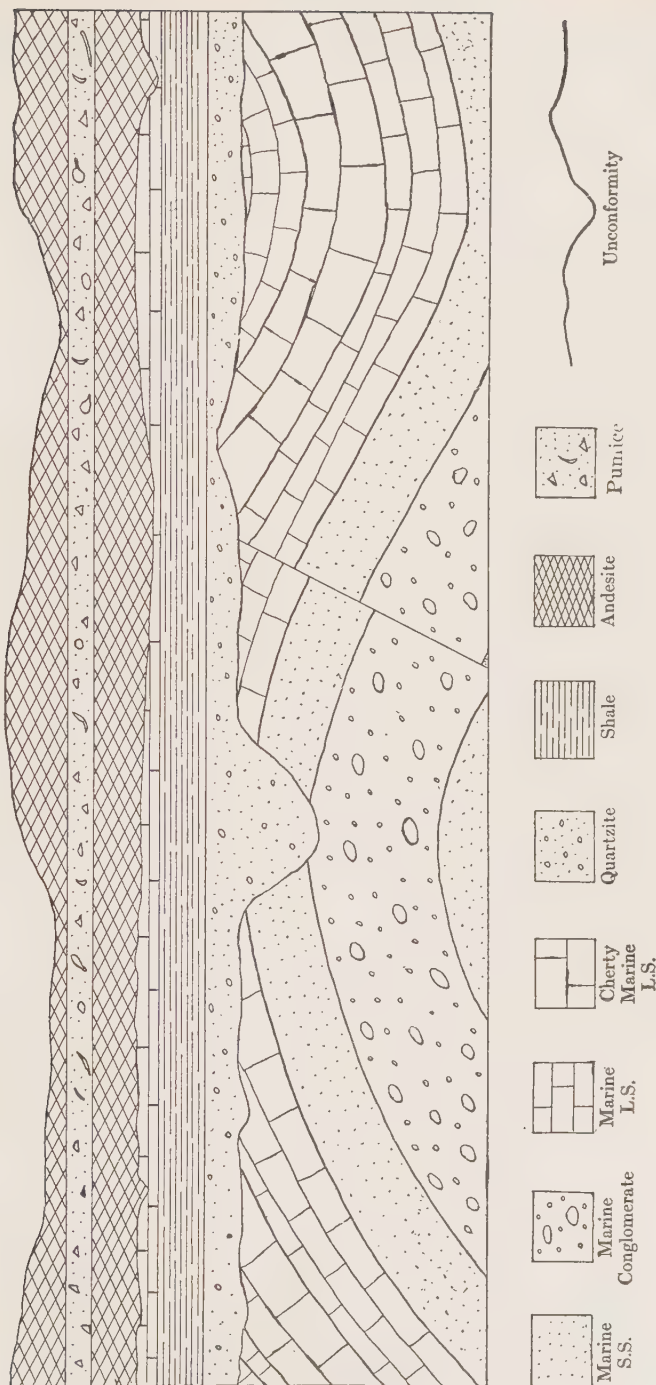




# PROBLEM 2



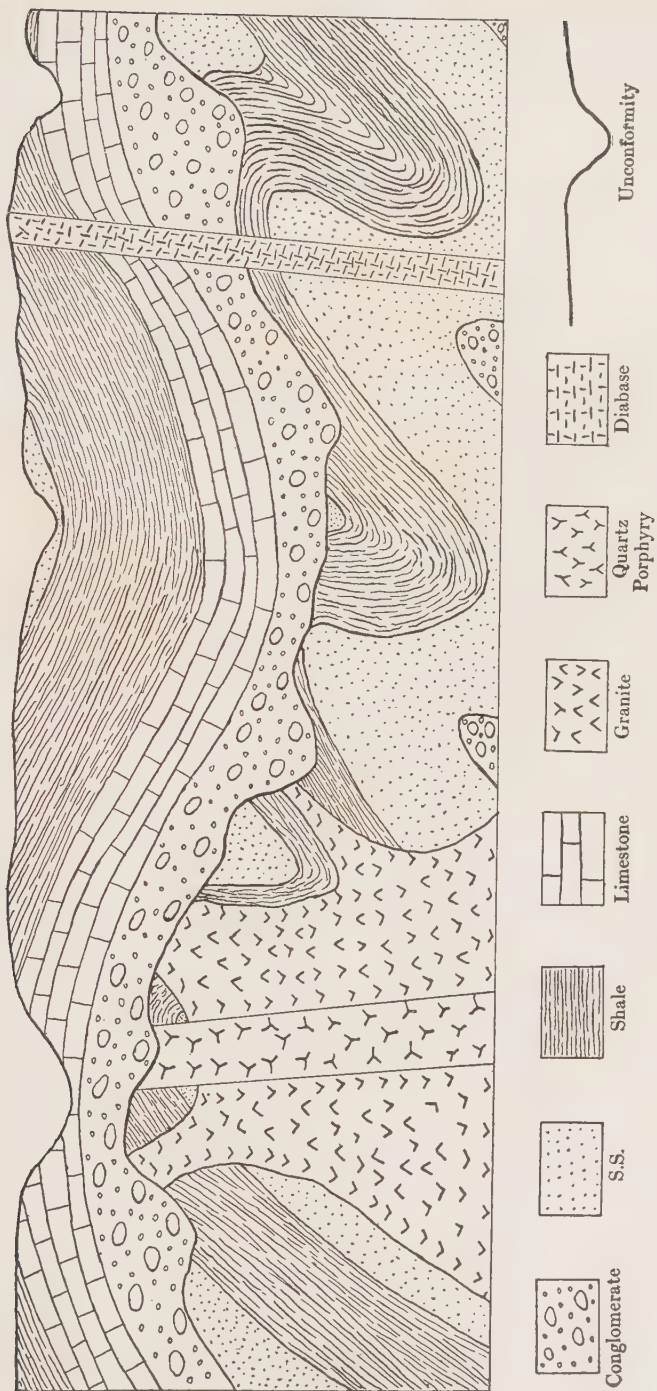
# PROBLEM 3



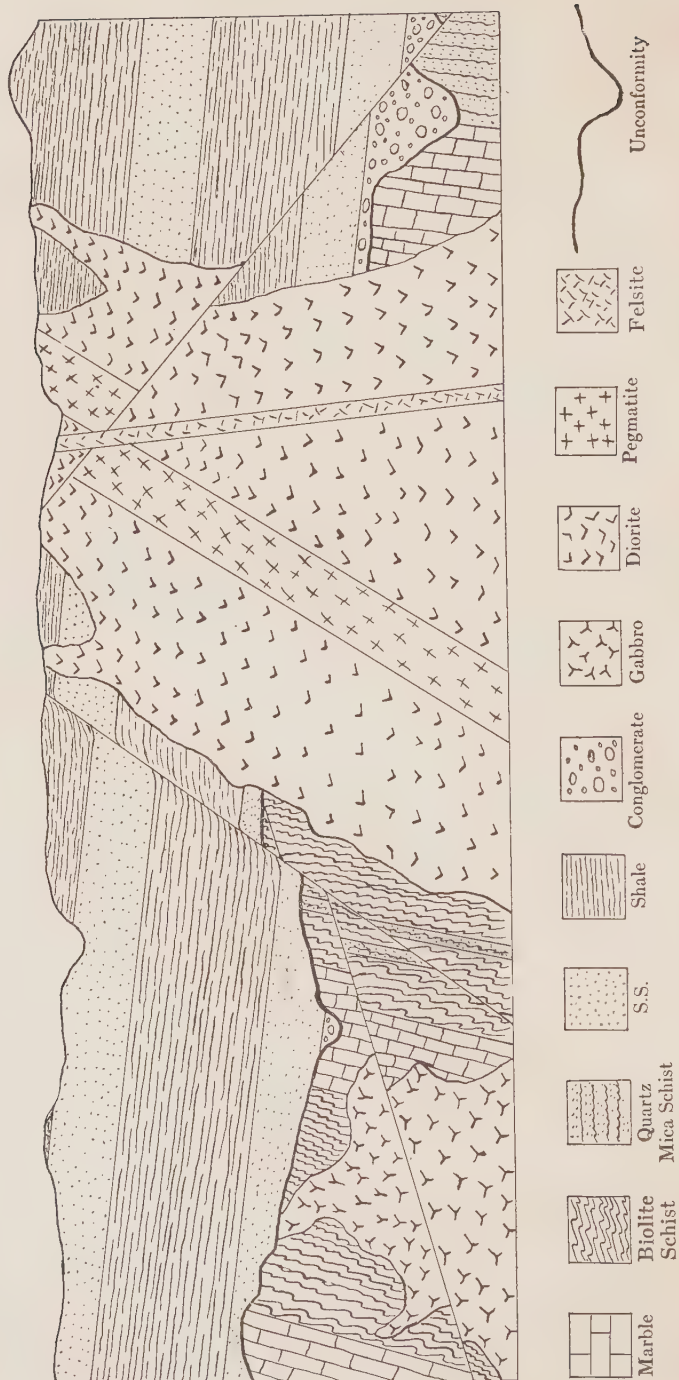
## 4



# PROBLEM 5



# PROBLEM 6





# STRUCTURE

NAME

DIVISION

DATE

# STRUCTURE

NAME

DIVISION

DATE

# STRUCTURE

NAME

DIVISION

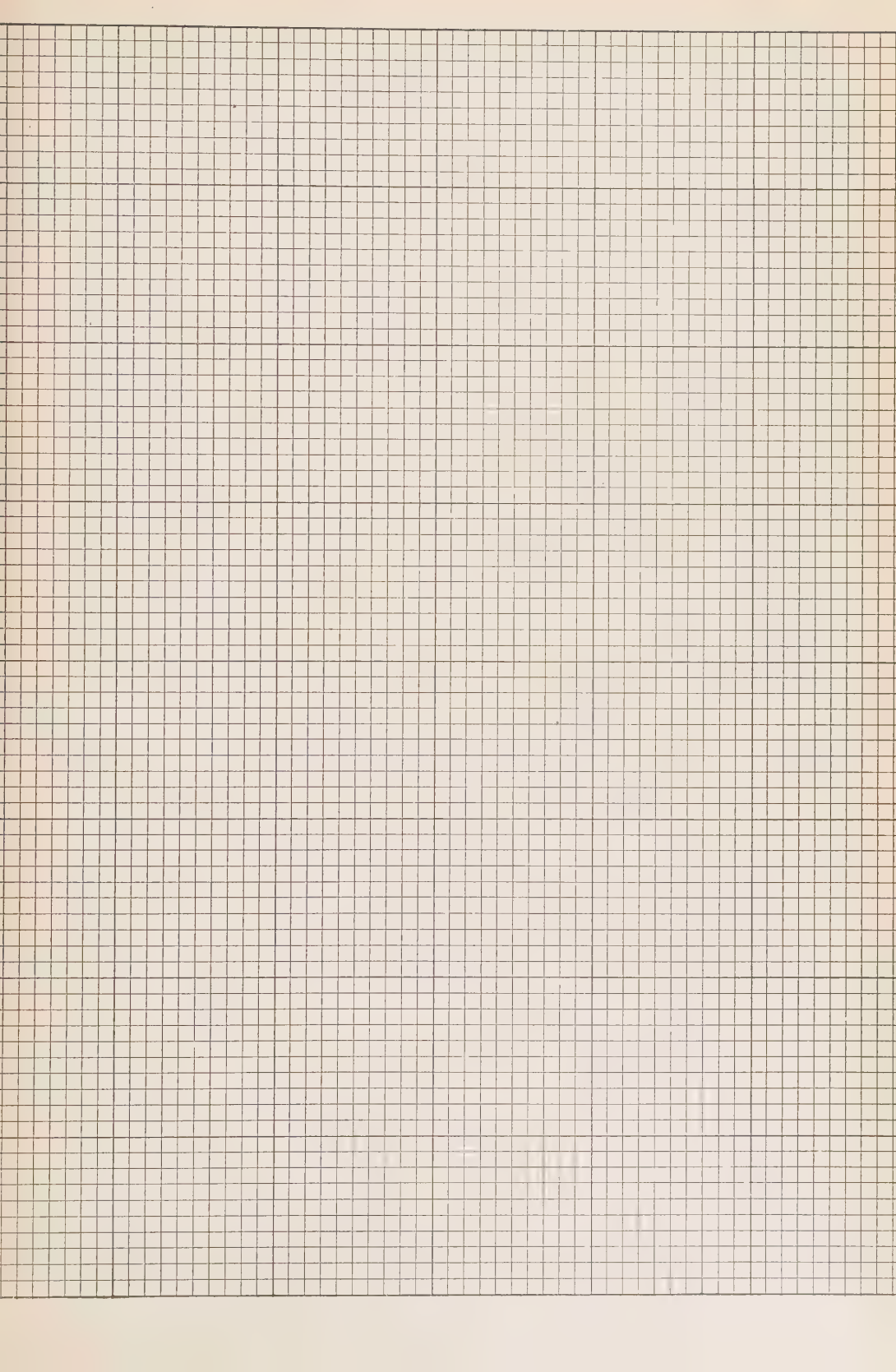
DATE

# STRUCTURE

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NAME

DIVISION

DATE

## INTRODUCTION TO THE STUDY OF ECONOMIC GEOLOGY

Economic Geology may be defined as the practical application of geology, especially to the production of useful or valuable materials. These valuable materials may be roughly divided into two groups:

### I. NON-METALLIFEROUS SUBSTANCES:

Such as coal, oil, building stones, and other substances used for commercial, chemical, and medicinal purposes, fertilizer minerals, and salts. The development of coal and oil deposits is largely dependent upon a careful study of the structures of the sedimentary rocks in which they occur; and oil geology is now considered a special branch of Economic Geology, requiring specially trained men. Certain of the non-metalliferous rocks are used for buildings and constructional purposes, such as roads (both macadam and concrete). The best road metals are the basic, fine-grained igneous rocks and the hard limestones. Why? The principal building stones are the light colored, granitoid rocks, limestones, dolomites, sandstones, gneisses and marbles. Which of the rocks that you have studied would you consider good building stones and why?

### II. METALLIC SUBSTANCES:

Such as iron, copper, lead, zinc, aluminium, etc. None of the metals (elements or alloys) are naturally abundant, with the exception of platinum, gold and copper, but occur as compounds. A mineral which is of economic importance is spoken of as an *ore mineral*, and an *ore* is a rock in which the valuable minerals are sufficiently abundant to make the rock worth mining. The following elementary exercise is to give you some practice in distinguishing some of the important ore minerals, and ores, together with their mode of occurrence. For a more comprehensive discussion of the general subject of Economic Geology see your lecture notes and text.

INSTRUCTOR'S REMARKS

## GEOLOGY MANUAL

### ESSENTIAL CHARACTERISTICS OF SOME COMMON ORE MINERALS

#### IRON ORES:

Over 90% of the iron ore minerals are of sedimentary origin or occur in sedimentary rocks. About 5% of the iron ore minerals consist of magnetite, which is associated with the igneous rocks.

#### FOSSIL IRON ORE:

Principal ore mineral is *hematite* or *siderite* (iron carbonate). The cementing materials are quartz and calcite. The "fossil iron ores" are either fossiliferous limestones, in which the shells have been replaced by iron minerals, or distinctly oölitic.

#### BOG IRON ORE:

Composed chiefly of hydrous iron-oxide, called *limonite*. Relatively unimportant but interesting as showing the way in which the sedimentary iron ores may have originated.

#### HEMATITE ORES ( $\text{Fe}_2\text{O}_3$ ):

Several varieties of which the *Red Ocherous* or *earthy hematite* are the most important in the United States. Red to reddish-brown streak. Soft. Common cement and coloring matter in sedimentary rocks.

#### MAGNETITE ORES:

Dense, highly crystalline ores in which the magnetite is cemented or held together principally by quartz. Magnetite ( $\text{Fe}_3\text{O}_4$ ) is black, magnetic and usually occurs as a granular aggregate of crystals shaped like double pyramids. Its hardness is 6 and it has a metallic luster.

#### SULPHUR ORES:

(Potential Iron Ores). Pyrite and Pyrrhotite.

#### PYRITE ( $\text{FeS}_2$ ).

For diagnostic characters see p. 32. Occur as nodules in shales and often as disseminated grains in sedimentary rocks. Also occurs as granular aggregates and disseminations, or massive, in veins. Some of the vein pyrites in the western United States carry gold which is only ascertainable by assay.

#### PYRRHOTITE:

Color, bronze yellow. Magnetic. Hardness 3.5-4.5. Often occurs disseminated or massive in veins.

## COPPER ORES:

There are three principal types of copper ore minerals; Native copper, copper carbonates, and copper sulphides. About 10% of the copper mined is native, 5% oxides, silicates or carbonates, and 85% sulphides. The important copper ores are usually associated with the igneous rocks or metamorphic rocks of igneous origin. Some ores are found in sedimentary rocks where they have been produced by contact metamorphism.

**NATIVE COPPER:** ( $\text{Cu}$ , metallic copper).

Red, malleable and ductile. Metallic luster. Hardness, 2.5-3. Native copper often occurs as thin leaves or irregular forms, and is the predominant ore in the lavas and conglomerates of the Michigan copper district.

**CHALCOCITE:** ( $\text{Cu}_2\text{S}$ ).

Color and streak, dark lead-gray. Hardness 2.5-3. Important ore in the southwestern United States and at Butte, Montana. An exceedingly rich ore mineral. Why?

**CHALCOPYRITE:** ( $\text{CuFeS}_2$ ).

A yellow, "brassy" looking mineral, sometimes difficult to distinguish from pyrite. Streak, greenish black. Hardness, 3.5-4.

**MALACHITE:** ( $\text{Cu}(\text{OH})_2 \cdot \text{CuCO}_3$ ).

Color, bright green; often with an "earthy" luster. Commonly occurs as crusts or stains on weathered outcrops of sulphide ores.

**CUPRITE** (Red copper ore).

Brittle. Hardness 3-4. Color, various shades of red. Occurs commonly as cubes, octahedrons (eight-sided crystals) and dodecahedrons (twelve-sided crystals). Easily distinguished from native copper by its brittleness. Earthy forms of cuprite may be difficult to distinguish from earthy hematite.

**AZURITE** ( $\text{Cu}(\text{OH})_2 \cdot 2(\text{CuCO}_3)$ ).

Differs from *malachite* in that its color is azure to deep blue. Both azurite and malachite are common but only locally occur in sufficient amounts to form important ore deposits.

## LEAD ORES:

The ore minerals occur as sulphides, sulphates, and carbonates, but the sulphides produce the bulk of the lead supply of the world. There are two principal types of galena deposits:

(1) the so-called "soft" lead ores, in which the galena is associated with the zinc ore minerals, and is relatively free from copper, and (2) more complex deposits of igneous origin, in which the galena is associated with a number of other metallic minerals. The latter, complex ores produce about 70% of the world's lead.

GALENA: ( $\text{PbS}$ ).

Silvery, metallic luster and pronounced cubic cleavage. Hardness 2-3. Heavy! Occurs in granular aggregates or disseminated in quartz or sulphides. Galena may carry silver in sufficient amount to greatly increase its value.

#### ZINC ORES:

Zinc never occurs in the native state but as either a sulphide, oxide, carbonate or silicate of zinc. Similar to the lead ores, the zinc ores are of two types: (1) associated with sedimentary rocks. (2) associated with igneous intrusions. The most important zinc ore mineral is the sulphide sphalerite or "zinc blende."

SPHALERITE: ( $\text{ZnS}$ ).

Color, usually yellow to brown with a resinous luster. Six cleavages! Hardness 3.5-4. Commonly occurs in granular aggregates or associated with other sulphides.

#### GOLD ORE:

Native gold ( $\text{Au}$ ) is the principal gold mineral. Native gold occurs either as a mechanical concentrate in gold placer deposits (auriferous river or beach gravels) or in quartz veins. Almost all vein quartz contains gold but usually in such small amounts as only to be distinguishable by assay. Gold may also occur in pyrite and in the silver-lead ores and in the complex sulphide ores.

## GEOLOGY MANUAL

### LABORATORY EXERCISE ON ECONOMIC GEOLOGY

- EXERCISE A. Review all the minerals and rocks listed in the previous exercises, which may be of economic importance. Study the named minerals in the trays containing common ore minerals, using the "Essential Characteristics of some Common Ore Minerals." You will be examined later as to your knowledge of these minerals, and their associations.
- or* Identify the numbered (unnamed) minerals and ores in the trays, using the "Essential Characteristics of some Common Ore Minerals." Enter your conclusions on the laboratory blank, facing p. 60.
- EXERCISE B. *(study)*
- or* Describe<sup>1</sup> and name the minerals and ores in your trays without reference to the text. Enter your conclusions on the laboratory blank, facing p. 60.
- EXERCISE C. *(test)*

<sup>1</sup> This test may be made to include all the minerals previously studied.

### TEST QUESTIONS

1. Define the following terms: Ore mineral, ore, native metal, economic geology.
2. What ore minerals are apt to be found together in ore deposits?
3. What are the principal ores of iron, copper, zinc, and lead?
4. Name all the different kinds of building stones used in the college buildings.

### INSTRUCTOR'S REMARKS





LABORATORY EXERCISE ON ECONOMIC GEOLOGY

NAME

DIVISION

DATE

Topography is a representation of the Earth's surface on a flat plane

# Essentials of a good map:

1. Accuracy
2. Precision
3. Reliability

Scale: (1)  $\frac{1}{2500}$  (2) 1 inch = 1 mile (3) 

Latitude and Longitude

## Kind of maps

- Physical map
- Topographical map
- Thematic map
- Reference map

## Map projection

- 1. Cylindrical
- 2. Conical
- 3. Planar

## Cartesian

- 1. Mercator
- 2. Robinson
- 3. Wulst
- 4. Mollweide
- 5. Hammer
- 6. Peters
- 7. Gall
- 8. Sinus Mundus
- 9. Sinus Terre
- 10. Sinus Orbis

## INTRODUCTION TO THE INTERPRETATION OF TOPOGRAPHIC MAPS

You have already been introduced to the materials which make up the surface or visible portion of the earth. You will now study the sculpture of the earth's surface. From the cultural point of view, this subject may be defined as the *scientific* interpretation of scenery. Unfortunately neither the season, nor the number of men in the course, nor the limited time at our disposal permit the teaching of this subject out of doors. Furthermore, no immediate region is so diversified as to illustrate all, or many of the important and most interesting features of the earth's surface. North America has been called the type continent of the world because all, or nearly all, the important geologic phenomena are well illustrated within its borders. Fortunately the United States government is actively engaged in mapping the area of its domain, and has already printed a large number of sufficiently diversified maps for our purposes. By using lantern slides and selected maps we shall try to bring the "field" into the laboratory. This method has the distinct advantage in that it not only teaches you to develop, but to curb and direct, your imagination, and thus increase your ability for *independent work*.

In attempting to make a picture of a portion of the earth's surface on paper it is necessary to use a method which will show not only the location or relative positions of important features, but also the rugosity or "roughness" of the earth's surface. Such a map is called a topographical map because it is an attempt at a three dimensional plan of the topography of an actual region. A map which does not show the topography of a region is called a plane or "flat" map and is of very little value to the geologist. Unfortunately most of our maps are constructed in this way, such as automobile and railroad maps, and therefore afford the user little or no idea as to the nature of the region which he has to traverse. There are several ways in which the physiography or topography of a region may be shown on a map. Each method has its specific use, but not all the methods are equal as to their accuracy.

### SHADING:

The method of using shading to illustrate the relief or topo-

graphy of a region is easy to read, and fairly effective on large maps but is altogether too generalized a method for even a reasonably accurate portrayal of the topography of a region.

#### COLOR:

Areas of approximately equal altitude are shown by different colors or shades of the same color, usually brown. Such maps are called hypsometric maps, and are fairly accurate (for large-scale maps) and easy to read. Many of the more popular maps (atlas and automobile maps) are printed in this manner. While of value to the traveller such maps are rarely sufficiently accurate to illustrate the land forms or (erosional) features of a region, and are practically useless as a base map for geological field work, the contour interval usually being too great, and the color interfering with the technique of mapping.

#### HACHURES:

Some cartographers, especially the French, shade their maps by means of lines drawn more or less parallel to the slope. The steepness of the slope is portrayed by close-spacing of the lines and vice versa. A well-executed hachure map is easy to visualize and reasonably accurate, provided there are enough figures to show the important elevations, but is not sufficiently accurate for most geologic purposes.

#### CONTOURS:<sup>1</sup>

The contour method is highly artificial but sufficiently accurate to illustrate the topographical features or "land forms" of a region. For this reason it is favored by physiographers and geologists, and forms an excellent basemap for geological field-mapping. Contour lines are usually shown in brown, in order to distinguish them from the "cultural" symbols which are black. A contour may be defined as a line of equal elevation; that is, every point on the line is at the same altitude. If you imagine the contour line as a level path around a hill, so long as you stay on that path you will always be at the same altitude. Contours must always close if followed continuously. When the contours come close together (closely spaced), a steep slope is signified and when they are far apart the slope is a gentle one. Contours which "run together" signify a cliff. Contours should never cross

<sup>1</sup> On some contoured maps differences of altitude are further emphasized by means of colors, areas lying between selected pairs of contours being colored according to a standard scale of "altitude tints," usually shades of green for low ground and brown for higher ground.

except in the case of an overhanging cliff. The shape or "swing" of the contours illustrates the topography of the region. The contour interval is the difference in elevation between two successive contours. This must not be confused with the actual distance between the contours on the map. The relation of contour interval to map scale is a very important factor in making a good topographic map. For further discussion of the use of contours read the back of any United States Topographic Map. You must learn to use a contour map not simply as a mechanical contrivance for determining the altitudes of certain points, or for plotting profiles, but as an illustration, or actual picture of the region which it represents. As you look at a contour map imagine that it represents an area over which you are flying in an aeroplane, at a sufficient altitude to see the whole area and yet not so high as to lose sight of the relief. You will probably have to practice for some time before you can rapidly visualize the country from the map, but the effort is well worth the trouble. Once you have learned to use a contour map you will prefer it to all other types.

#### PROFILES:

A method for constructing profiles is illustrated on *Plate VIII. Figure 1* is a contour map (contour interval = 20 feet) showing an elliptical hill at the east end of the map (relief = 60 feet) rising from an oval platform, 40 feet above base level. A depression, over 40 feet deep, is shown by depression contours at the west end of the map. The method for making a longitudinal profile along the line *A,B* is shown in *figure 2*. Drop perpendiculars from all intersections of the contours with the profile line, *A,B* on the coordinate or lined paper *A<sup>1</sup>,B<sup>1</sup>*. Let the vertical coordinate or vertical distance between lines on the profile paper (from the base up) equal 20 feet. Where each projection intersects its proper vertical coordinate (horizontal line) make a dot or cross. Sketch a line through the dots or crosses and complete the profile. When the length of the section, or horizontal distance, does not have to be magnified you will find it convenient to lay off the distances between the contours along the straight edge of a slip of paper and transfer the measurements to your parallel-ruled, or coordinate paper. Always put the compass points, such as N., S. or E., W. on your profile, as well as the relation of the vertical to the horizontal scale. On most maps a one-to-one, or natural profile, will appear alto-



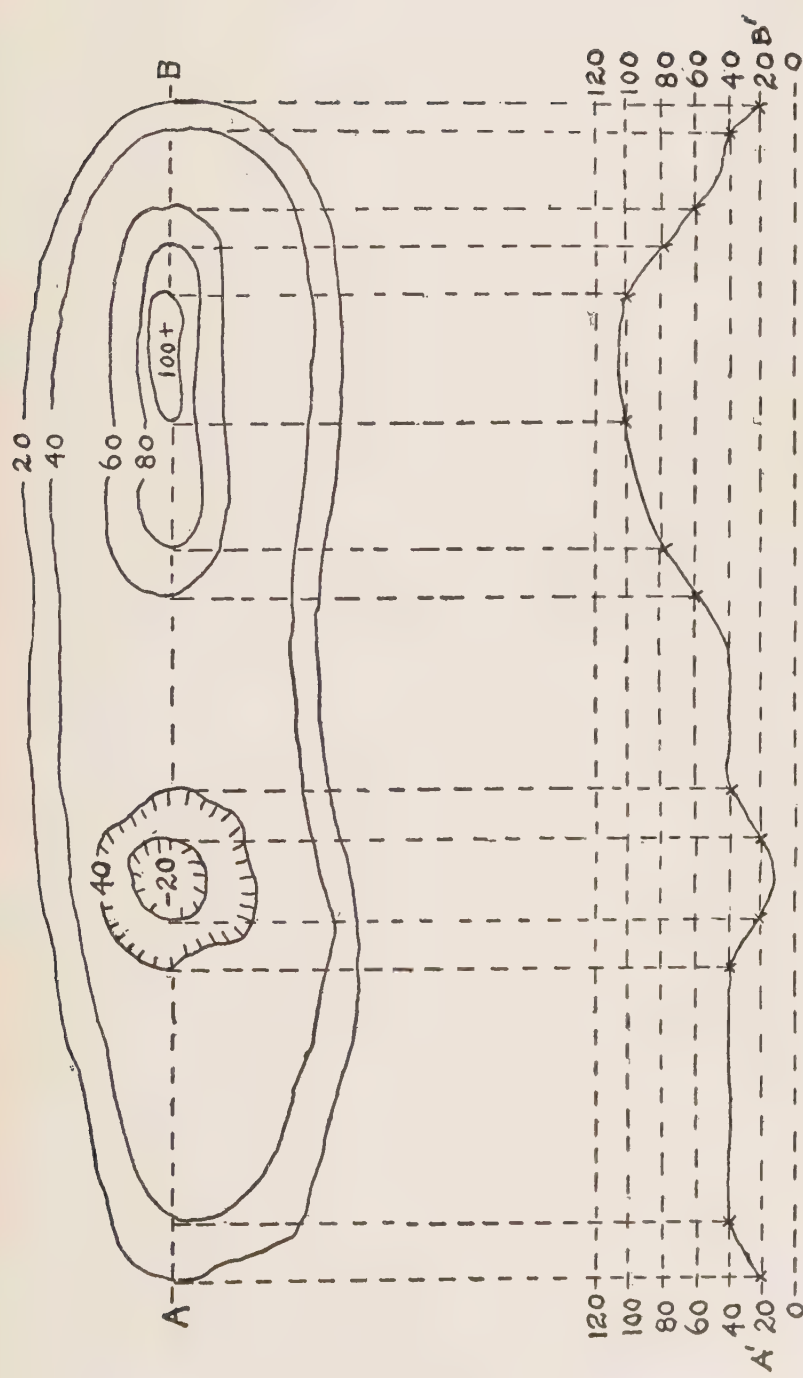
gether too flat. On the other hand too great a vertical exaggeration will make apparent mountain peaks out of what are really low, rounded hills.

#### TOPOGRAPHIC MAPS:

The United States issues two kinds of maps, Topographic and Geologic. The former show, by conventional symbols, the configuration of the earth's surface, also drainage, culture, etc. The latter show the surface and sub-surface distribution and arrangement of the materials (formations) which make up the outer portion of the earth's "crust." During the first term of the introductory course we shall use only a few geologic maps.

As the student progresses in his work, he will discover that the topographic maps illustrate not only distinctive physiographic features, such as hills, valleys, and all other land forms, but also their origin and evolution. In short, topographic forms will be considered broadly as the product of three factors: (1) *Process*, (2) *Stage*, and (3) *Structure*. By *process* is meant the agent which produces the form, and its mode of operation, such as the action of a river in cutting its valley or in building a sand bar. By *stage* is meant the degree of success which the agent has attained in completing its work. For instance, a river which has succeeded in cutting a valley from the edge backward into a high plateau is still in a youthful stage; for the ultimate possibility of river erosion in this region would be the reduction of the plateau to a peneplain (nearly a plain). The manner in which this would be accomplished cannot be discussed until later, but the student must realize that given *sufficient time* such would be the case; provided that the work of the stream and its tributaries is not interrupted by some other process which did not enter into the original set of conditions. As we shall see later, such interruptions do occur and tend to complicate the normal cycle of erosion in a most interesting way. By *structure* is meant the physical character and relations of the rock, as for instance, folded sedimentary rocks, horizontal sedimentary rocks, jointed granite, stratified alluvium, etc. Structure is an exceedingly important factor in determining stream patterns and land forms. Ultimately, the student may be able to predict the structure of an area by interpretation from a topographic map alone, but a geologic map is usually necessary, and always exceedingly helpful. In this introductory course, however, attention will be

PLATE VIII.



Upper portion is Figure 1. Lower portion is Figure 2.

## PROFILE PAPER

## COMPASS DIRECTION?

## LINE OF SECTION?

## COMPASS DIRECTION?

## COMPASS DIRECTION?

## LINE OF SECTION?

## COMPASS DIRECTION?

## GEOLOGY MANUAL

paid to *process* and *stage*; the study of the relation of land forms to structure more properly belongs in more intensive courses in Physiography and Structural Geology.

The United States Geological Survey since 1886 has published over 3000 engraved topographic maps, representing nearly 43% of the area of the United States. Eight states—Massachusetts, Rhode Island, Connecticut, New Jersey, Delaware, Maryland, West Virginia, and Ohio—have been completely mapped, and important portions of each of the other states have been covered. The topographic map forms the base for the geologic map, which is also being prepared. When both the topographic and geologic maps have been completed, they are bound together with a concise description of the general geology of the district, both economic and scientific, to form a “folio” of the “Geological Atlas” of the United States. The number of folios published to date (1924) is 218. Topographic maps are arranged alphabetically in the laboratory folder. Thirty-seven (37) of these maps showing typical geologic phenomena, or the results of geologic processes, are described in this Manual. Many of the described maps illustrate several phases of the work. The maps in the second folder show similar phenomena, but are undescribed, and will be used for original and independent study. The student will first study the described maps, asking questions of his instructor or fellow students. When the student feels that he is fully prepared, he will study the undescribed maps *independently*. If the student does his best to follow the procedure outlined above, his corrected laboratory work will be of real value and not merely a completed exercise. ~~Whether or not he does follow the above suggestion will automatically show in the grades which he receives in his laboratory tests.~~

### IMPORTANT:

Please handle the folders and maps as carefully as you can. The maps are valuable and difficult to replace. All your laboratory work must be done in pencil. Do not use a fountain pen. Do not make any marks on any of the maps. Help to keep down the cost of replacement of laboratory materials. *Remember! you will also be an alumnus some day and interested in the cost of running your University!*

## GEOLOGY MANUAL

### TOPOGRAPHIC FEATURES:

The following topographic features are particularly emphasized on the described maps, and are listed under the same headings. You will be required, not only to recognize these features on both the described and undescribed maps, but also to describe the features either by means of sketches, contours, or linear and transverse profiles.

#### 1. WIND WORK

- sand dune
- barchan
- blow-out
- mesa
- butte

-natural levee

-deposits on convex curves

-cut-offs - *close particular channels*

-sand bar - *deposits*

-delta

#### 2. RIVER EROSION

- digitate drainage
- trellis drainage
- river terraces
- piracy
- V-shaped valleys
- mesa
- butte

#### 5. GROUND WATER

sink or swallow hole

underground stream

border spring

rock dam spring, cienega

fissure spring

contact spring

pocket spring

mesa spring

#### 3. CYCLE OF EROSION

- young stream and region
- mature stream and region
- old age stream and region
- entrenched meander
- rejuvenation

#### 6. MOUNTAIN GLACIATION

glacier

lateral moraine

terminal moraine

medial moraine

tarn

U-shaped valley

finger lake

cirque

cycle of cirquation

comb ridges

#### 4. RIVER DEPOSITION

- alluvial fan
- bolson - *the surface of 2 confluences 1 alluvial*
- interior drainage
- flood plain and scrolls
- playa - *formed at bottom of a*
- oxbow lake
- braided stream - *a number of interweaving channels*

NOTE: Depression contours are usually used to illustrate the following: (a) volcanic crater, (b) "blow-out," (c) sink hole, (d) kettle hole.

## GEOLOGY MANUAL

### 7. CONTINENTAL GLACIATION

drumlin  
U-shaped valley  
fiord (shore line)  
post glacial gorge  
finger lake  
misfit stream  
terminal moraine  
esker  
kame  
aimless drainage  
outwash plain  
kettle hole (pit lake)  
delta (dissected)

### 8. SHORE LINES

ria coast  
fiord & fiard  
tidal islands  
cusped bar  
lagoon  
bay-mouth bar  
hooked spit  
lake terrace  
marine terrace  
cliff  
barrier beach  
tidal delta  
tombolo

### INSTRUCTOR'S REMARKS



## GEOLOGY MANUAL

### PRELIMINARY LABORATORY EXERCISE ON THE READING OF TOPOGRAPHIC MAPS

- I Read the instructions on the back of any topographic sheet and study the conventional signs for water, relief, and culture.
- II From a careful inspection of the Chief Mountain quadrangle answer the following questions:
- (1) One inch on the map equals how many inches in the field? How many feet? How many miles? 1:125,000
  - (2) What is the magnetic declination?
  - (3) What is the "fall" of McDonald Creek from its source to Lake McDonald?
  - (4) Of the two tributaries, Mineral Creek and Avalanche Creek, which has the steeper gradient? (Note: Gradient is measured in feet drop per mile.)
  - (5) Copy in a three-inch square a tributary stream pattern with its associate contours, labelling the valleys and spurs.
- III From a careful inspection of the Bright Angel Quadrangle answer the following questions:
- (1) What is the R.F.? *representative frad.*
  - (2) What is the difference in degrees, between true north and magnetic north?
  - (3) Draw a transverse profile (location to be designated by instructor).
- IV What are the essentials of a good topographic map?

NOTE: Be sure that you understand all the terms and symbols associated with topographic maps, especially: Contour, topography, reentrant, relief, gradient, magnetic declination, contour interval, map distance, representative fraction, or R.F., culture, transverse and longitudinal profiles, quadrangle.

### INSTRUCTOR'S REMARKS

2      LABORATORY EXERCISE ON TOPOGRAPHIC MAPS

NAME

DIVISION

DATE



NAME

DIVISION

DATE



## INTRODUCTION TO THE STUDY OF WIND WORK ON TOPOGRAPHIC MAPS

THE wind is an especially effective geologic agent in arid climates or in regions where there is a constant supply of fine, loose or loosely consolidated material. The work of the wind is both destructive (corrasive) and constructive. The destructive or corrasive form of wind action is especially effective in semi-arid or arid regions, such as deserts, intermontane basins, and high plateaus where there is insufficient moisture to support a vegetable blanket or protective cover for the products of disintegration.

### FORMS DUE TO CORRASION:

Where the wind has free play and can pick up dust and sand, it uses these fine-grained materials as tools to corrade or carve the harder formations into forms which are more or less typical of desert regions. The characteristic profiles of topographical features to be found in arid regions are illustrated on *Plate IX*. The student should realize that all of these forms probably did not originate through the work of the wind alone, but were partly evolved by the work of rain, or streams now either extinct or flowing at a lower level. It is also true that the structure, and the character and degree of consolidation of the formations, are important controlling factors in the formation of desert profiles. This applies particularly to mesas, buttes, and rock terraces, which, by the way, are the only corrasive forms of sufficient magnitude to be shown on topographic maps.

### FORMS DUE TO ACCUMULATION:

The constructive work of the wind is best illustrated (1) in deserts (low or high level), (2) in certain intermontane valleys, (3) in certain river valleys, and (4) along certain coast lines. For the convenience of the student the maps will be discussed according to the above classification and not according to rainfall or amount of aridity. The conditions governing the origin of the sands differ for each locality, but the methods of accumulation and the topographic forms evolved are more or less common to all. In short, any region, no matter of how small an area, which is covered with shifting sands, may be properly described as a desert. The characteristic forms of aeolian (wind-



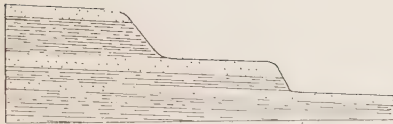
blown) deposits are shown on *Plate IX*, *figs. 6-9*. Hills or mounds of wind-blown sand are called *dunes* and may be shown on a topographic map in several ways, depending on the contour interval. If the dunes are low and their altitude is less than the contour interval, the pattern used for their portrayal is made up of brown dots arranged in such a way as to illustrate the general form of the deposit. An area which is covered with shifting sands is usually characterized by a more or less hummocky topography. Where the contour interval is less than the relief of the dunes, the hummocky topography is well illustrated by ordinary and depression contours. You will find in the succeeding exercises that depression contours are also used to illustrate sink holes (work of ground water), kettle holes (continental glaciation), and volcanic craters. Further, when the aeolian topographic features are not well defined but blend together to form a rough, hummocky topography, it may be difficult to distinguish this type from a somewhat similar topography, the result of continental glaciation. A final check on your conclusions is the location and general character of the region:

(1) Is the region outside the glaciated area of North America? (Note, however, that owing to the large amount of sand and fine material washed out from a retreating (melting) continental glacier, extensive deposits are formed which, if not protected by a vegetable cover, yield an abundant supply of material for the work of the wind, even in fairly moist climates.)

(2) Are there other striking evidences of aridity, such as (a) scarcity of rivers or streams; (b) intermittent streams; (c) playa or intermittent lakes; and (d) streamless springs?

## INSTRUCTOR'S REMARKS

PLATE IX.



Rock Terraces

1



Mesa

2



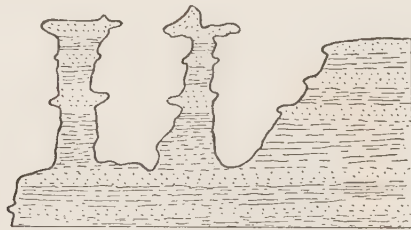
Butte

3



Alluvial Bench

4



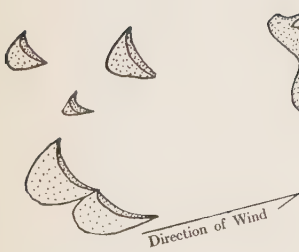
Castellated Chimneys

5



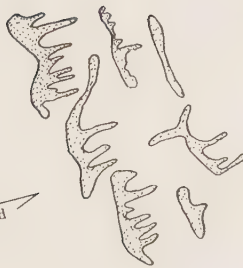
Barchan

6



Barchans

7



Transverse  
Dune Ridges

8



Longitudinal  
Dune Ridges

9

## GEOLOGY MANUAL

### *List of Described Maps Showing Wind Work*

- |                    |                         |
|--------------------|-------------------------|
| (1) Disaster, Nev. | (5) Minneapolis, Minn.  |
| (2) Tularosa, N.M. | (6) Islip, N.Y.         |
| (3) Tusayan, Ariz. | (7) Provincetown, Mass. |
| (4) Paxton, Neb.   |                         |

### INTERMONTANE DESERTS:

These are well illustrated by sheets (1) and (2). The deserts are located in basins between high and well dissected ranges. The average rainfall is about 10 inches. Most of the streams are intermittent, showing interior drainage which either evaporates in their lower courses or sinks into the unconsolidated sediments of the valley fill or plain. The interior basins contain extensive *alkali flats*, or *playas*. In (2) the "white sands" have been derived from the alkali flats on the west. The "sands" are quartz sand dunes which contain a relatively large proportion of gypsum. The whole alkali flat is a more or less level, desert surface, part of which is never covered with water, and is scoured by the wind to the approximate depth of the ground-water table, below which the wind loses its power of corrasion. The *malpais* is the exceedingly rough surface of a lava flow which has flowed down the valley from the north. In the southeast corner we have the phenomenon of a lake-basin-deposits highly modified by wind work, for it is only during the wet season that the basin is occupied by an ephemeral lake. In (1) the sand dunes in the southwest corner have been blown from the surface of the playa and outwash plains, but are less than 200 feet high, as is indicated by the absence of contours. The Quinn River is an excellent example of a stream which is well supplied with water at the source but "disappears" in the Black Rock Desert, due to evaporation and percolation.

### HIGH LEVEL DESERTS:

(3) This area lies within the Colorado Plateau district. The larger part of the surface has an elevation of about 6000 feet. Above the general level, large and small areas (mesas and buttes) rise 200 to 600 feet or more. The map suggests that the lower portion of the area, standing at 6000 feet, was developed by the reduction of a plateau whose surface corresponded with the elevations represented by the tops of the buttes and mesas, or by the reduction of a still higher surface. Only one stream is

shown on the map, the Little Colorado River, which is comparatively weak and insignificant. If the 6000-foot plateau is the work of streams, the map would suggest that the surface which now stands at this altitude is much higher than when it was developed. The absence of a well-defined drainage pattern on the other hand, raises the question whether wind work may not have been an important factor in the degradation of the surface from the higher to the lower level.

The cliffed elevations, the absence of streams, and the disappearance of the water of the springs soon after issuing, all point to aridity.

#### RIVER VALLEY DESERTS:

(4) This particular area is located in the "Sand Hill Region" of the Great Plains of western Nebraska, where the rainfall is about 20 inches. The semi-aridity of this section is intimated in the topography by the absence of many streams and the evidence of wind work as shown by the great number of depression contours. Many of the small mound-like elevations shown north of the North Platte River are sand dunes. The hachured contours represent depressions which have been scooped out by the wind. South of the river the dunes are formed largely of sand swept out of the river valleys. The scarcity of water in the valley of the South Platte is due to the fact that its headwaters have been tapped for irrigation. On sheet (5) the flat southwest of Deans Lake is a terrace, and the ridges between Deans Lake and the river valley are sand dunes derived from the river sands and gravels. The growth of peat in the depressions of the dune-sands tract tends not only to form swamps, but also to raise gradually the level of the groundwater area with the result that the peat finally covers the dunes, stopping further wind action.

#### SHORE DESERTS:

(6) Off the south shore, separated from the mainland by long, narrow lagoons, there are two beaches, Fire Island and Oak Island. The work of the waves is aided by the wind, which raises the sand above the level of the highest storm waves and sweeps it inland. The lagoons behind the beaches are gradually being filled, principally, by wind-blown material. Small, well developed, but constantly shifting dunes, are shown on the beaches. These dunes must be less than 20 feet high. Why?

## *GEOLOGY MANUAL*

Shore line dunes are also well shown on (7). The long narrow ridges lying north of the rough hilly topography of the western portion, and south of the relatively flat beach of deposition, may be interpreted as sand dune ridges.

### INSTRUCTOR'S REMARKS

## GEOLOGY MANUAL

### LABORATORY EXERCISE ON WIND WORK

#### *List of Undescribed Maps*

Atlantic City, N.J.  
Hutchinson, Kans.  
Lakin, Kans.

Moses Lake, Ore.  
Satsuma, Tex.  
Tarida Ranch, Tex.

1. Give a careful and detailed description, using sketches wherever possible, of the topographic features on each of the undescribed maps which are due to the work of the wind. In discussing each map consider:
  - a) different possible sources of the dune sand.
  - b) different heights and shapes of the dunes in relation to the amount of sand and force and direction of the wind.
  - c) general effects of wind scour.Label your sketches accurately, and indicate the name of the map from which each example is copied.
2. Study the demonstration specimens illustrating the work of the wind.
3. Describe and sketch a "Dreikanter" pebble which has been carved by wind work.
4. Be sure that you can illustrate and define the following terms: barchan, depression contour, dreikanter, dune, blow-out, corrasion, mesa, butte, playa, intermittent stream or lake.

#### INSTRUCTOR'S REMARKS





## LABORATORY EXERCISE ON WIND WORK

NAME

DIVISION

DATE



LABORATORY EXERCISE ON WIND WORK

NAME

DIVISION

DATE



LABORATORY EXERCISE ON WIND WORK

| NAME | DIVISION | DATE |
|------|----------|------|
|------|----------|------|





## INTRODUCTION TO THE STUDY OF RIVER AND REGIONAL EROSION ON TOPOGRAPHIC MAPS

THE work of rivers and streams is both destructive and constructive. The destructive work of streams sculpts the surface of the earth into a variety of forms. So long as a land surface (continent) remains above sea level, it is subject to the destructional work of rivers. The hills are not "everlasting," and rugged or mountainous country will ultimately be reduced to sea level or "base level." Such a surface will be "nearly a plain" (peneplain). Rivers are the principal agents of sub-aerial denudation, and the study of river patterns and land forms (Physiography) comprises an important branch of general geology. For a full discussion of the work of rivers, see your lecture notes and text. Also read again the introduction to the interpretation of topographic maps. The erosion pattern of any region will depend, not only upon the kind and degree of erosion to which it has been subjected, but also upon the structures which are being eroded. Thus, the erosion of a folded region will develop different types of stream patterns, valleys, hills, or mountains from a region in which the formations are horizontal, or a region in which there have been intruded a number of relatively resistant igneous rocks. You will not have time in this exercise to study the relation of stream or regional erosion to different types of structure, but only in areas of relatively horizontal formations, or where the bed rock is relatively uniform in its resistance to erosion.

### RIVER VALLEY EROSION:

Rivers, and the valleys which they cut, may be clearly shown to have a life history or cycle of development which is distinctly evolutionary. Curiously enough, it has taken man much longer to appreciate that land forms have evolved than it has for him to develop the general theory of the evolution of organisms. You must prove to your own satisfaction that most streams occupy valleys which they have developed themselves, and that streams lengthen their valleys by headward erosion. You will see that streams and their valleys are "born," "grow up," and "grow old," and that the study of any great stream valley, such as the Mississippi, shows that it becomes more youthful as you

trace its course from its mouth to its origin in the distant mountains. Thus we can study the "life history" (ontogeny) of a stream in much the same way that we study the life history of an organism. You will study maps which illustrate all degrees of stream erosion, and once you have learned to interpret the "swing" of the contours you will have little or no difficulty in visualizing the peculiar characters of the land surface. In order to gain an exact knowledge of the inequalities of a land surface, it is necessary to construct profile sections, but our experience has been that a student soon learns to *visualize* the country without the extra labor entailed by drawing profiles, provided he studies a sufficient *number* of maps.

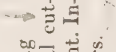
#### CYCLE OF RIVER VALLEY EROSION:

Stream valleys, as illustrated by topographic maps, may portray either youth, maturity, or old age. Certain valleys may also show evidence of an interrupted cycle. This feature may also be ascribed to rejuvenation. In order to facilitate your study of topographic maps in terms of the cycle of river erosion, the criteria for the determination of each cycle are arranged in the form of a table (p. 81). You are expected to memorize this table.

#### CYCLE OF REGIONAL EROSION:

In humid regions where there is sufficient run-off to develop river systems, we have the cycle of regional river erosion from youth, through maturity, to old age. Here again, the development of the characteristic topographic features of the early stages is largely controlled by the underlying structure of the region. We shall only consider the general types, such as are developed in flat formations or those of uniform character and hardness. In the early stages there are a few youthful streams. As the regional erosion progresses, the number of streams increases, largely by the development of tributaries, until a typical finger-like or digitate stream pattern is formed which produces a well dissected region with short valleys running in all directions. From now on there is a reduction of the number of tributary streams by capture or piracy, with the result that the headwaters of some streams are diverted to increase the headwaters of others. Finally, in old age we have left only a few master streams, which may be likened to the "survival of the fittest." If the region is not subjected to uplift or depression, it will

# RIVER EROSION CYCLE

| STAGE        | STREAM EROSION                                                                                                                                                         | LONGITUDINAL PROFILE                                                                                                   | TRANSVERSE PROFILE                                                                | PECULIAR FEATURES                                                                    |
|--------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|
| YOUTH        | Downward cutting dominant.<br>                                                      | River and valley slopes ungraded. Falls, rapids and lakes may be present.                                              |   | Steep valley sides and gorge forms. Cliffs, and slopes ungraded by talus.            |
| MATURITY     | Downward cutting slight. Lateral cutting beginning<br>                              | Falls, rapids and lakes have disappeared. Narrow flood plains and meanders appear. River and valley slopes are graded. |   | Valleys more open than in youth. Valley slopes moderate and often masked with talus. |
| OLD AGE      | Lateral cutting dominant.<br>                                                       | Stream sluggish as it approaches base level. Minimum drop of feet per mile. Strongly aggrading in lower reaches.       |  | Valleys very open and valley slopes exceedingly gentle.                              |
| REJUVENATION | Downward cutting dominant. Lateral cutting also important. In-trenched meanders.<br> | Valley which has an old age or meandering pattern and a steep sided or youthful transverse profile.                    |                                                                                   |                                                                                      |

eventually be reduced to base level (nearly sea level). Such an old-age land surface is conveniently called a peneplain (nearly a plain). Sometimes an area or region shows evidences of rejuvenation (uplifted peneplain). Such an uplift may not have been continuous, but cyclic, so that we may postulate, not only one, but two or three periods of rejuvenation or peneplanation. This is evidenced by entrenched meanders and successive valley levels, or by the accordance of summit levels. In order to facilitate your study of topographic maps in terms of regional erosion, the criteria for the determination of each cycle or stage are arranged in the form of a table (p. 84). You are expected to memorize this table.

INSTRUCTOR'S REMARKS

*List of Described Maps Showing River and Regional Erosion*

- |                                        |                         |
|----------------------------------------|-------------------------|
| (1) Euclid, Ohio                       | (4) Kaaterskill, N.Y.   |
| (2) Echo Cliffs, Ariz.                 | (5) Monterey, Va.-W.Va. |
| (3) Bright Angel, Ariz.                | (6) Little Rock, Ark.   |
| (See description on back<br>of sheet.) | (7) Hahnville, La.      |
|                                        | (8) Lockport, Ky.       |

## YOUTH:

Young stream valleys are well illustrated in Euclid (1). The terraces shown on this map are of comparatively recent origin (see explanation under "Shore Lines") consequently the streams which cut their margins have been eroding their valleys but a short time, geologically speaking. Note the steep valley sides in the unconsolidated sediments of the lake terrace and the gorges in the hard rock escarpment behind. The valleys in the second terrace are still short but are being rapidly lengthened by the *headward* erosion of the streams. The tributaries are in a still earlier stage, although the *digitate* or finger-like type of stream pattern is beginning to develop. Euclid Creek above the town of Euclid is an excellent example of a youthful stream and its tributaries. The valleys are typically V-shaped in transverse profile, with steep walls. The lengths of the younger tributary valleys are short compared with their widths and depths, which is what we should expect in the case of youthful stream valleys. Below Euclid, Euclid Creek is flowing nearly at grade, as is shown by the nearly flat transverse valley profile and somewhat meandering course, which becomes more so as it approaches Lake Erie. The streams of this region are eroding their valleys in gently dipping, nearly horizontal formations.

In *Echo Cliffs* (2) we see an excellent illustration of youthful or canyon river valleys, and also youthful regional erosion. The most conspicuous feature of the map is the deep, narrow valley or canyon of the Colorado River, which has been cut down through almost flat-lying sedimentary rocks. This valley is from 2000 to 4000 feet deep, and not over a couple of miles wide at its narrowest point. Deep as the valley is, it is youthful, for it is narrow and steep-sided, and such valleys are in the stage of youth, whether deep or shallow. Youth is also emphasized by the broad, gently sloping upland plateau which has as yet not been eaten into by the young tributary streams to any extent. Aridity is indicated by the almost entire absence of streams, except the



# PLATE XI.

## REGIONAL EROSION

| STAGE                              | STREAM PATTERN                                                                           | PROFILE                                                                            | RELIEF                                                                                       |
|------------------------------------|------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------|
| YOUTH                              | Few youthful streams.                                                                    |   | Increasing relief.                                                                           |
| EARLY MATURITY (ADOLESCENCE)       | Numerous branching streams. Digitate or dendritic pattern developing.                    |   | Stage of maximum relief. Original surface (peneplain) indicated by concordant summit levels. |
| MATURITY                           | Complex, ramifying network of streams. Completion of digitate pattern, piracy beginning. |   | Relief decreasing.                                                                           |
| OLD AGE                            | Great reduction in number of master streams.                                             |   | Minimum relief.                                                                              |
| REJUVENATION or INTERRUPTED CYCLES | Dependant upon time of rejuvenation.                                                     |  | Maximum variation of reliefs throughout the region. Peneplains of more than one cycle.       |

Colorado River, which has its source in the Rocky Mountains where it is continually fed by melting snows, and therefore has a permanent source of supply enabling it to maintain its course through the arid lands. The student must consider the scale of the map in order to appreciate the grandeur of the features represented. Marble and Glen Canyons may be entrenched meanders (evidence of rejuvenation) because the Colorado River may have inherited its course from an old age stage in the cycle of erosion. Whether or not the course of the river is inherited, its erosive power has been created by relatively recent uplift and it is rapidly (geologically speaking) deepening its valleys, and increasing its length by *headward erosion*. The Grand Canyon is probably one of the finest examples of the power of river erosion in the world. Once the student has really appreciated the fact that the Colorado River has cut the canyon in which it now flows, he will have grasped a fundamental geological truth upon which rests a large part of modern geological philosophy. For an excellent description of a youthful region, read the description on the back of *Bright Angel* (3).

#### MATURITY:

Number *Kaaterskill* (4) is rather more complicated than the preceding maps, but is introduced particularly to illustrate a mature region together with special types of stream pattern. There are two types of topography shown on this map; (1) the low hilly area on the east with a well defined NNE-SSW trend and a rectangular or *trellis*\* stream pattern; and *Echo Cliffs* (2) the mountainous topography on the west without definite trend and with a *digitate* stream pattern. The eastern area lies within the province of the folded Appalachians, and the probability is therefore that the trend of the hills results from the linear distribution of the hard and soft sedimentary beds. The western area lies within the province of the Appalachian plateau, and this fact, together with the digitate pattern of drainage, suggests uniformity of underlying rock, in this case gently-dipping sedimentary beds.

Note that several of the northern tributaries of Kaaterskill Creek, near their headwaters, start off as though they were going to join a stream draining westward into Gooseberry Creek, but near their mouths they turn abruptly and join

\* For description of "trellis" see p. 86.

Kaaterskill Creek. Such a tributary pattern of drainage suggests that these streams actually did at one time flow into Gooseberry Creek but were later captured by the headwaters of Kaaterskill Creek which, with its steeper gradient, worked headwards very rapidly and diverted the drainage to the east. Stream capture such as this is called *piracy*. Eventually Kaaterskill Creek may even capture the main branch of Schoharie Creek beyond Tannersville.

Another sheet to illustrate maturity is *Monterey* (5). This area lies within the Appalachian mountain province. The drainage and erosion topography are mature; that is, the valleys are developed to such an extent that nearly all the surface has been "reduced to slope." The principal topographic features have a prominent northeast-southwest trend. This peculiar topography is due to the fact that the region is underlain by rock layers of unequal hardness, which have been folded and eroded so that the edges of the hard layers form the ridges. The valleys have been developed in the softer and more easily eroded beds, and the harder rocks stand out as ridges, because the less resistant beds adjacent to them have been worn away to lower levels. The ridges have not been "thrown up," but the beds surrounding or bordering the ridges have been cut down. The streams that cross the outcropping belts of hard rock cross them at right angles, or nearly so, flowing through these belts for as short a distance as possible. The tributaries enter more or less at right angles; so that if a sketch, in plan, is made of the drainage system, the pattern resembles that of a trellis such as is used to support vines, or a fireman's ladder, and is often called "*trellis drainage*."

#### OLD AGE:

A characteristic old-age stream is well illustrated in *Little Rock* (6). The topography south and southeast of Little Rock resembles that of a plain, and implies relatively flat-lying sediments. The description (see back of map) states that they are layers of unconsolidated sand and clay dipping gently to the southeast, with the exception of Fourche or Granite Mountain, which, as the name implies, is formed of hard and relatively resistant igneous rock. This area is at the northern border of the gulf coastal plain and hence near the lower waters of the drainage system of which the Arkansas River forms a part. Note

the old-age characteristics, such as meandering course, oxbow lakes, swamps, etc. The phenomena of the work of an old-age stream are well illustrated by *Hahnville* (7). The map is too small to more than hint at the general character of the Mississippi in its lower course. The stream is nearing its delta. Obviously, as we ascend a stream, its valley will tend to become less mature and we find that the heads of its actively eroding branches or tributaries are expressed in youthful valleys. A single river system may illustrate all stages of river development, becoming progressively "older" as it nears its mouth. Note that the river is not eroding at this point but is flowing on its own deposits. The origin of the river bed will be discussed in the next exercise (River Deposition).

#### REJUVENATION:

Maturity and rejuvenation are well illustrated in *Lockport* (8). The topography of this district as a whole represents a region in a "mature" stage of river erosion. The meandering character of the Kentucky River, which is a characteristic feature of the stage of "old age," therefore appears anomalous. Two cycles of erosion are represented on this map. If the river valley were filled to the general level of the hilltops, we would have a peneplain (nearly a plain). Such a form is developed in the stage of old age at or near sea level. Upon this former peneplain the Kentucky River and its tributary, Elkhorn Creek, formed their meandering courses. Subsequently uplift took place, but at such a rate that the main river and its larger tributary were enabled to cut down and maintain their former meandering course, thus giving us the types known as *entrenched meanders*. Meanwhile the peneplain, now raised to the elevation of a plateau, has been dissected to a mature stage of erosion by the minor tributaries. The meanders are therefore inherited from a previous old-age stage in the cycle of erosion, whereas their "entrenchment" is obviously due to the quickening of the stream. The quickening with its resultant greater erosive power, could only be accomplished by increase of gradient (rejuvenation). Increase of gradient could only be produced by uplift. Hence an "entrenched meander" is evidence of regional uplift, and in this case denotes the beginning of a new cycle before the completion of the earlier one.



## GEOLOGY MANUAL

### EXERCISE ON RIVER EROSION<sup>1</sup>

Phenomena connected with river erosion as shown on maps:

- A. The cycle of stream erosion, or youth, maturity, and old age of streams and their valleys.
- B. The cycle of regional erosion, or youth, maturity, and old age and rejuvenation of river systems.

#### *List of Undescribed Maps Showing River Erosion*

Aitkin, Minn.

New Haven, Ill.

Diamond Creek, Ariz.

Pikeville, Ky.

Golconda, Ky.-Ill.

#### *Written Work*

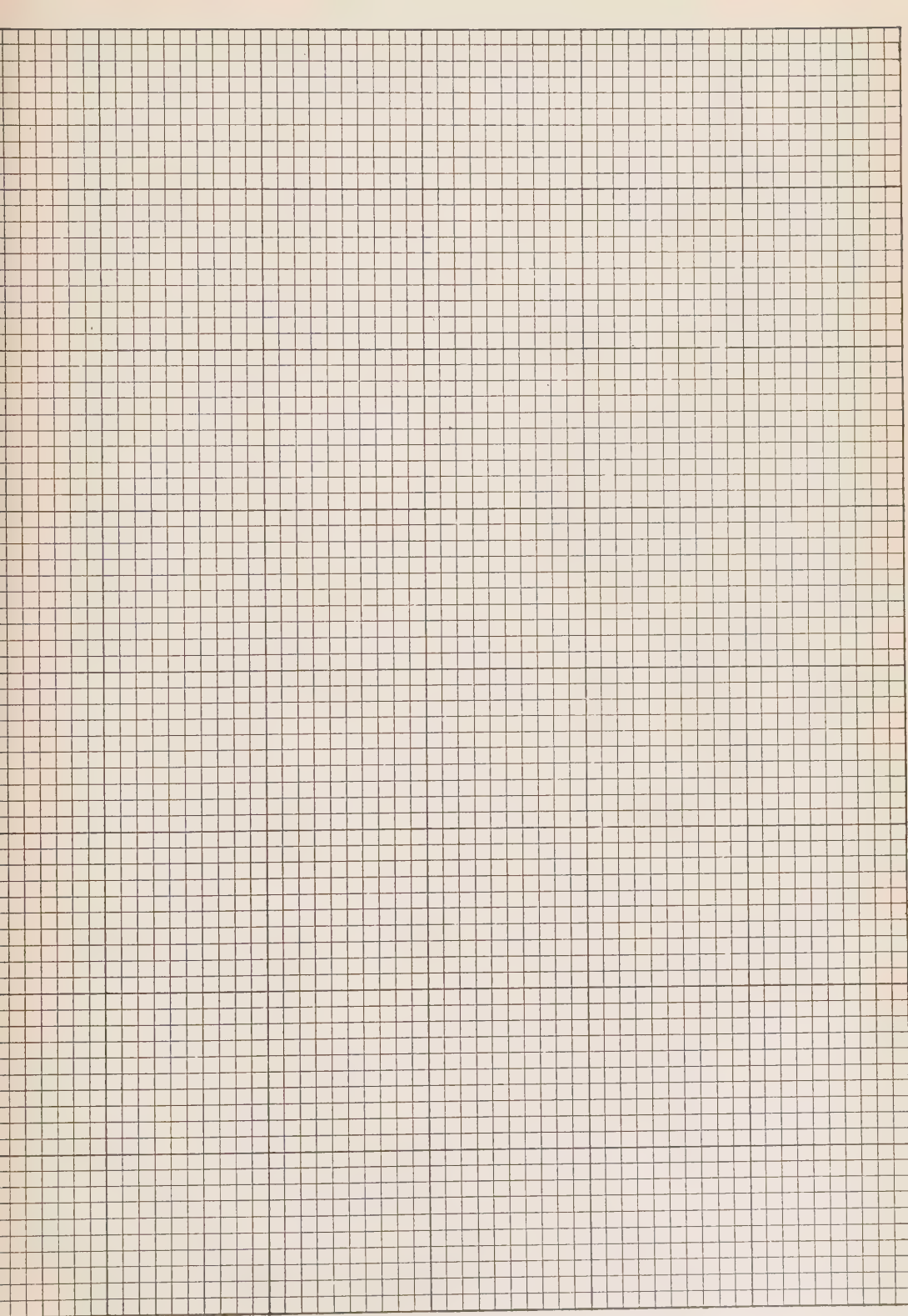
From the undescribed maps answer the following questions with specific reference to each example chosen:

1. Locate and describe a typical example of each of the following stages of River Valley Development: (a) youth, (b) maturity, (c) old age. The written description should, in each case, include all important and diagnostic characters.
2. Name and describe a map for each of the following stages in the cycle of regional erosion: (a) youth, (b) maturity, (c) old age. The written description should, in each case, be illustrated by suitable profiles (accurately labelled) and include all important and diagnostic characters.
3. Name and describe a map which illustrates rejuvenation of a mature or old age state. The written description should include a clear statement as to your method of reasoning.

NOTE: Be sure you understand the following terms: cycle of stream and regional erosion, youth, maturity, old age, rejuvenation, entrenched meanders, V-shaped valley, piracy, differential erosion, trellis drainage, peneplain, stream pattern, digitate drainage, headward erosion.

<sup>1</sup> For an Introduction to River and Regional Erosion in folded areas, see p. 141.

#### INSTRUCTOR'S REMARKS







NAME

DIVISION

DATE



## INTRODUCTION TO THE STUDY OF RIVER DEPOSITION ON TOPOGRAPHIC MAPS

IF we follow the course of any master stream, such as the Mississippi, from its mouth to the source of any of its branches, we will find that it is not always actively engaged in eroding its bottom and banks. At times, and in certain places, much of its work is depositional. This is particularly true of a stream which is not yet flowing at grade and where there are a number of local base levels or lakes along its course which lessen its carrying power and act as local catch basins. As the erosion of the region continues these local deposits will be eventually carried to the sea. Not all continental deposits are destroyed during the complete cycle of regional erosion, but it is probably true that strictly river laid or channel deposits form only a relatively small proportion of the older formations. River sediments begin their march to the sea as cliff breccias and the talus from the steep mountain slopes. Much of the material, especially in arid or semi-arid regions, is moved in large quantities only during the rainy season. Ultimately the finer material is washed within the reach of the deeper and more permanent streams, and except for local halts, is finally deposited in some standing body of water, either fresh or marine. The above description does not take into account the large amount of material which is removed in solution.

### STREAM DEPOSITION:

Only the large rivers develop individual depositional features which are large enough to be expressed on our topographic maps, and these only in the maturer parts of their courses. Usually it is not until the river begins to meander that depositional features, such as bars and terraces, are developed. Exceptions to this are when the river flows into a lake, where it builds a delta; or is unable to carry its load, either because it is surcharged with material or because it is flowing over a temporary base level. In the latter case it is apt to be "lost" in its own deposits; and forms many shifting channels which are called *braided streams*. Most of the depositional features illustrated on the topographic maps are the result of intermittent or temporary streams which often become raging torrents in the rainy

season or during cloudbursts. It is at this time that the bulk of the clastic material is transported on the lower mountain slopes, the Piedmont zones facing high ranges and in intermontane basins.

#### REGIONAL DEPOSITION:

The most extensive areas of river deposits at the present time are those forming the "outwash" plains in front of long mountain ranges, or filling large intermontane valleys. These deposits are apt to be modified by wind work, and often contain intercalated lake or playa deposits; but the bulk of the transportation and accumulation is undoubtedly due to the work of numerous streams which emerge from the steep mountain canyons and which are effective agents of transportation and deposition only during the rainy season. The resultant torrential deposits form a complex system of interlacing channels or network of stream gravels and sands which build a series of sub-aerial alluvial fans or cones in front of their respective canyons. As these cones grow they tend to coalesce, not only with each other, but also with those being formed on the opposite side of the valley, with the result that the valley is gradually filled with a great series of confluent alluvial fans or sub-aerial deltas. The central portion of the valley may either contain a sluggish master stream or ephemeral or playa lakes. For a further discussion of River Deposition, see your text and lecture notes.

#### INSTRUCTOR'S REMARKS

## GEOLOGY MANUAL

### List of Described Maps

- |                         |                          |
|-------------------------|--------------------------|
| (1) Paxton, Neb.        | (7) Hartford, Conn.      |
| (2) Waukon, Ia.-Neb.    | (8) Ballarat, Cal.-Nev.  |
| (3) Marshall, Mo.       | (9) Cucamonga, Calif.    |
| (4) Donaldsonville, La. | (10) Mt. Whitney, Calif. |
| (5) Jonestown, Miss.    | (11) Tularosa, N.M.      |
| (6) Watkins, N.Y.       | (12) Disaster, Nev.      |

### RIVER DEPOSITION:

Sheets (1), (2) and (3) show good examples of river channel deposits. On *Paxton* (1) both the North Platte and the South Platte show evidences of deposition. This is indicated in the larger stream by the islands, and in the smaller by its anastomosing or *braided* channels. The several subordinate channels of the South Platte are continually being choked by sediment which the currents cannot carry, and the water then breaks out into new courses. The numerous channels are thus constantly shifting. The headwaters of the Platte River are in the Rocky Mountains, where the steep slopes enable them to carry a large load. Where they come out upon the high plains, their velocity is checked and their ability to carry their load is thereby decreased, resulting in partial deposition. Overloading of a stream may result from (i) location of stream in loose or easily eroded sediments, (ii) variable supply of water, (iii) change of grade, or (iv) "tapping" for irrigation. Although not shown on the sheet, the South Platte is largely affected by (iv). Notice the number of canals in the North Platte Valley flat.

*Waukon* (2) shows a characteristic flood plain of a large stream where its valley is not very wide. The topography of the adjacent uplands is still in early maturity. The anastomosing channels and the ponds are characteristic of the flood plains of streams and these features are unusually striking in the area shown on this map.

Note that valley widening is in progress, or would be but for the protection afforded by the structures of man. At the north end of the area mapped, the river is working against its left bluff. It would doubtless be undercutting if the base of the bluff were not protected by a securely built railway embankment.

Harper's Ferry and Prairie Du Chien are built on river terraces in the main valley, and so are above the reach of disastrous floods.



*Marshall* (3) represents an area which is in the "old age" stage of river erosion. The country is relatively flat, and the streams meander in a broad alluvial flood plain. The bars and islands in the channel of the Missouri River indicate that deposition is now in progress. The lakes on the flood plain indicate former sites of the channel.

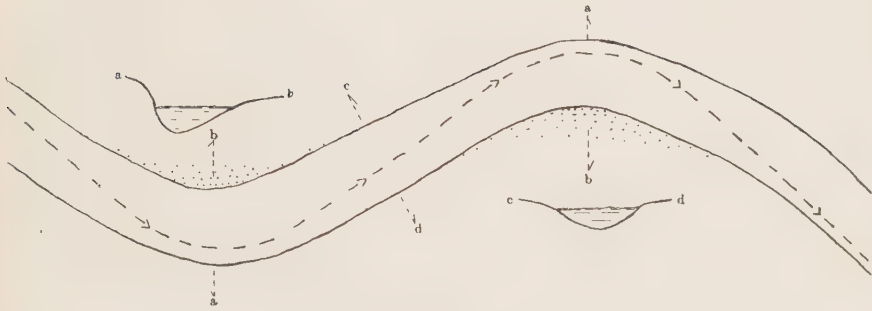
*Donaldsonville* (4) shows a portion of the course of the Mississippi where the river is doing little erosion but much "transportation" and "deposition." At first glance it seems curious that the surface of the river should be higher than most of the surrounding alluvium which it has deposited.

One of the most conspicuous features on this map is the white area ( $1\frac{1}{2}$  to  $2\frac{1}{2}$  miles wide) of higher land bordering the river, in contrast to the lower swampy areas farther away. Notice that the highest portion of this bordering land is that which is immediately adjacent to the banks of the river. The inference is that the higher land has actually been built up above the level of the swamp by the river itself. In time of flood the Mississippi may overflow its banks unless restrained by artificial levees. Under such circumstances the velocity of the overflowing water will be checked by friction and, most abruptly, at the point where it first escapes from its channel. Therefore the immediate banks of the river should be the principal site of deposition. The way in which this takes place is beautifully illustrated by the alluvial deposit or "delta-fan" which was formed when the Mississippi broke through the natural levee at Nita Crevass. In many places the height of those natural levees has been increased and their gaps have been filled by human agency to protect the surrounding country against flooding. Notice the relation of culture (roads) to natural levees.

*Jonestown* (5) illustrates a portion of the flood plain of the Mississippi with its ox-bow lakes, cut-offs, and flood plain scrolls or "ridge and swale," resulting from uneven distribution of the alluvium as the old age stream meanders among its own deposits. The scrolls may or may not contain lakes (bayous), and are shown by depression contours. Flood plain scrolls may grade into perfect ox-bow lakes.

The area shown on *Watkins* (6) lies within the so-called "Finger Lake Region" of western New York State. At the head of Seneca Lake there is a flat corresponding in width to that of the lake. This flat is a delta, being an area which was formerly

PLATE XII.



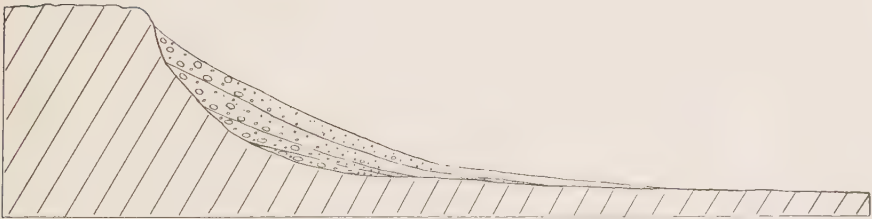
1

Plan and transverse profiles of a meandering stream which is cutting its banks at *a* and depositing bank-bars at *b*.



2

Cross-section of delta deposit laid down in a standing body of water. Compare the structures shown in this diagram with those of the sub-aerial delta (alluvial fan or bolson).

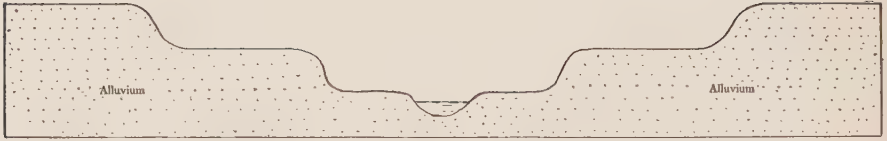


3

Cross-section of alluvial fan. Notice overlap at both ends of section.

After Hobbs and Lahee.

PLATE XIII.



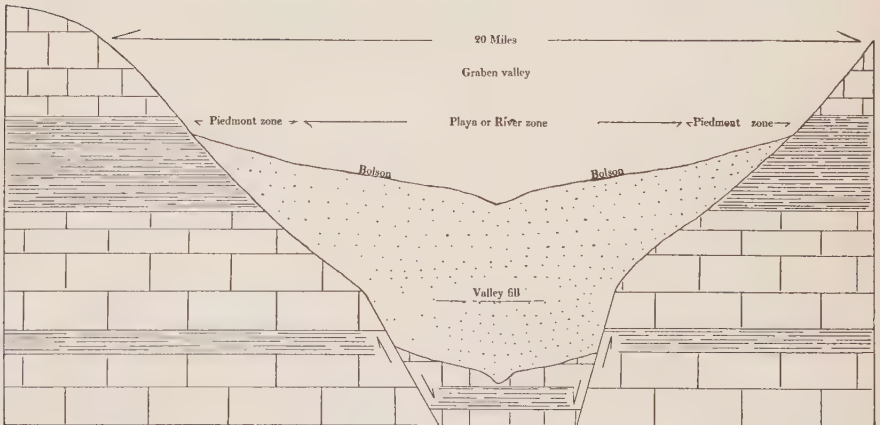
1

Dissection river or lake terraces. It is sometimes difficult to determine whether the terraces are developed in hard rock or alluvium.



2

Cross-section of depositional stream bed in the levee region.



3

Cross-section of an intermontane valley which is gradually being filled by a series of confluent fans. The old valley may be either erosional, structural, or both. What is the sequence of events in the above diagram?

a part of the lake, but which has been converted into land by the deposition of sediment brought down by streams.

*Hartford* (7) is a good illustration of river terraces. Note the contrast between the two types of topography shown on this map. In the southeast and northeast there are more or less rounded elongated hills. In the wide central portion and along the river are extensive flat areas located considerably above the level of the river. Flat areas also occur immediately adjacent to the river and less than a contour interval above it. The latter belong to the present flood plain of the river. The higher flats may be inferred to be terraces in varying stages of dissection by the streams working backwards from the main river. There are, at some points in this district, two terraces instead of one on each side of the river, one being at about 120 feet and the other at a lower elevation. Both of these terraces are remnants of former plains, the higher terrace representing the older plain. A topographic map does not always make it clear whether terraces are developed from older flood plains or in other ways. We may be sure, however, that the Connecticut River once flowed in a higher and somewhat broader valley than at present. It is not always possible, without a geological map or field evidence, to determine whether terraces are cut in alluvium or solid rock. How would you attempt to determine this problem from the map alone?

#### REGIONAL DEPOSITION:

*Ballarat* (8) shows several complete examples of *valley fills* or intermontane deposits whose desert surfaces or *bolsons* are clearly defined by the closed and relatively widely spaced contours. The basins have a N.W. and S.E. trend which has been proved to be parallel to the fault lines of the region. The basins originated as *grabens* or down-faulted blocks (see *fig. 3, Plate XIII*), which are being filled with the sheet wash derived from the bordering mountains. The special features of the bolsons, which will be discussed in detail in the succeeding maps are: (1) character of slope, (2) interior drainage, (3) ephemeral lakes and playas. (4) sand dunes. In Saline Valley Small Salt Lake is shown to expand to some two miles in diameter during a heavy rain in the mountains, or during the wet season. The sand dunes on either side of the dotted line are blown from the dried surface of the *ephemeral lake* or *playa*. The canyons in the border-

ing mountains contain intermittent streams (dotted blue lines) whose waters, when they emerge from the narrow canyons, rapidly sink and are lost in their deposits (shown by the pattern of the brown dots). The interior flat of Death Valley is several feet below sea level as shown by the closed, *minus contours* near the bench marks.

*Cucamonga* (9) represents a mountainous region on the north, and a bordering plain on the south. The topography of the highland is in its early maturity or adolescence, and has been developed by stream erosion, whereas the plain has a slope due primarily to sedimentation. The crenulate courses of the contours on the plain, and the relation of the curves to the valleys leading out from the mountains, tell the history of the topography of the plain. Each stream descending from the highland builds an alluvial fan (or cone) where it issues from its mountain valley, for at that point its diminished gradient does not allow the current to carry all of its mountain load. Over any such fan the contours should curve outward from the mountain. By growth, these alluvial fans have merged into one another laterally, and the result is a *compound alluvial fan or piedmont alluvial plain*, the *surface* of which is called a *bolson*. Piedmont alluvial plains of the type shown on this map are found in similar situations in all parts of the world. Long, relatively narrow, intermontane or interranger valleys are often filled to a considerable depth in this manner.

The major factors affecting the deposition of material at the foot of the steep mountain slope are four in number; (I) decrease in velocity due to lessened slope and distributary character of the streams, (II) loss of volume through seepage into the porous gravels and sands, (III) loss of volume through evaporation under the relatively arid conditions, and (IV) extreme variability in storminess and hence in run-off.

*Mt. Whitney* (10) is an interesting example of a valley-fill with its typical plain or bolson with a sufficiently humid climate to support a master stream. Owens Valley is a V-shaped trough, whose bottom is filled to a considerable depth with unconsolidated alluvial debris carried from the steep confining mountain faces by running water. There is reason to suppose that the gravel-filling near Independence is more than two thousand feet in depth. The trough in which this deposit lies was formed by faulting and tilting. The western face of the trough is the



granite escarpment of the Sierra Nevada, and the eastern face is composed of the sedimentary and igneous rocks of the White Mountains.

In general, lake and river deposits occupy the lower portions of the valley, and coarse mountain-wash, the upper edges, a zone of interbedded fine and coarse material lying between. The cones at the base of the Sierra Nevada form a continuous slope, and are of immense size, arising to a maximum elevation of two thousand feet above the river and extending out into the valley for three to seven miles.

*Tularosa* (11) illustrates an arid region with interior drainage. This quadrangle lies within the Great Basin Province. The mountain ridges and basins have originated directly through faulting and fracturing of the earth's "crust." This province is characterized by interior drainage, and most of the basins are floored with deposits of gravel, sand, and clay brought down from the mountains, locally to the depth of one or two thousand feet. Great aridity is indicated by the disappearance of the rivers by seepage into the valley-fill, and by the absence of many streams.

According to Powell, the largest ephemeral lake of Nevada is formed during winter months on what is known as Black Rock Desert, *Disaster* (12). This desert is over one hundred miles long, and its average breadth is twelve or fifteen miles. In summer it has no streams, except such as are fed by hot springs. In winter many brooks descend the mountains and the channel of the Quinn is a veritable river, whereas in summer the Quinn is shown only by a dry channel with an occasional water hole. When in flood the waters of the Quinn spread out on Black Rock Desert and at times form a long narrow lake four hundred to four hundred and fifty square miles in area. At times the "lake" is a vast sheet of liquid mud. The playas left by the desiccation of the lakes are always barren. Not a plant takes root in their baked and hardened surfaces. In summer the surface becomes white with salts, brought from below by capillarity and left on the surface when evaporation takes place. The bulk of such incrustations consist of sulphate and carbonate of soda, common salt, etc.



## GEOLOGY MANUAL

### LABORATORY EXERCISE ON RIVER DEPOSITION

#### List of Undescribed Maps

|   |                     |   |                           |
|---|---------------------|---|---------------------------|
| 1 | Aitkin, Minn.       | 6 | Hachita, N.M.             |
| 2 | Baton Rouge, La.    | 7 | Renault, Ill.-Mo.         |
| 3 | Cohoes, N.Y.        | 8 | Seattle Special, Wash.    |
| 4 | Golconda, Ky.-Ill.  |   | <del>Valdez, Alaska</del> |
| 5 | Granite Range, Nev. | 9 | Hyde                      |

1. Describe (using profiles and diagrams when helpful) all the phenomena of River and Regional Deposition previously studied, as *best illustrated* on any of the undescribed maps listed above. Be sure, in every case, to name the map and the exact locality of the phenomena which you describe.  
(or)
2. Name and locate all the phenomena illustrated on each of the undescribed maps listed above.
3. Be sure that you understand all the following terms: flood plain, bar, terrace, deposit on convex curve, braided stream, playa, natural levee, meander, flood plain scrolls, delta, alluvial fan, oxbow-lake, piedmont, bolson.

INSTRUCTOR'S REMARKS

LABORATORY EXERCISE ON RIVER DEPOSITION

NAME

DIVISION

DATE



3      LABORATORY EXERCISE ON RIVER DEPOSITION

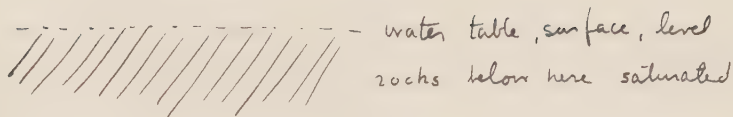
NAME

DIVISION

DATE



Vadose



Atlantic City is fed by 4,000 ft artesian wells.

aquifer - any formation pervious to water circulation.

Juvenile (magmatic) - waters which have not been on the surface before

## INTRODUCTION TO THE STUDY OF UNDER- GROUND WATER ON TOPOGRAPHIC MAPS

MOISTURE which is precipitated from the atmosphere and falls upon the ground in the form of rain either runs off in the form of streams, or sinks through the porous surface until it reaches the saturated zone called the groundwater table. Sometimes the descent of the surface water is arrested by a hard and relatively impervious layer such as a clay bed, lava flow, etc. In this case the impervious layer causes the more porous overlying bed to act as an aqueduct or aquifer, and if it is tilted the water will flow along it until it emerges on a hillside or is brought to the surface once again by an impervious obstruction, fault, or by artificial means such as a driven well. Even though springs are found high up in the mountains, the water which feeds them must have been derived from still higher levels, a fact that is sometimes difficult of comprehension even in the field. The work of underground water is twofold, for it acts both as a solvent and as a precipitant. In certain regions the springs are called mineral springs because they contain relatively large amounts of gas (carbon dioxide) or salts, such as ferrous and calcium carbonates. In places, due to the changes in temperature, pressure, and escape of the gas, the carbonates or silicates are precipitated forming deposits around the mouths of springs (calcareous tufa and siliceous sinter) or in caverns (stalactites and stalagmites). The latter are found in limestone regions, such as the Mammoth Cave area in Kentucky, and in numerous other localities throughout the Appalachians. Since limestone is more soluble than sandstone or shale, the surface water tends to enlarge existing open spaces, such as joints, and develop numerous underground channels. Sometimes the underground galleries or caverns are enlarged to such an extent that their roofs fall in and sink holes are developed. The sink holes afford still greater opportunity for the surface waters to pass underground and increase the sub-surface drainage. In the case of hot springs or geysers, the water may be either meteoric (derived from the surface) or juvenile (derived from the interior). The periodicity of certain geysers, such as Old Faithful in Yellowstone Park, suggest that a large part of the water was derived from mag-



# PLATE XIV.



Ideal profile, or structural diagram illustrating different types of springs.

## GEOLOGY MANUAL

matic water vapor. For further discussion of underground water, springs, and geysers, see your lecture notes and text.

For the purposes of map study, you will find it convenient to analyze each map as to whether the streams tend to disappear underground through sink holes or arise from the ground in the form of springs. Some sink holes are blocked sufficiently to become reservoirs and, when small, look something like springs. The relation of the stream to the contours will quickly determine whether the stream is running into the ground or out of it, and hence whether the body of water is a sink hole or a spring. Underground streams are seldom shown on topographic maps, but their presence may often be inferred by other features which have been described above. For illustration of the different types of springs which you will be expected to recognize on a topographic map, see the profile and structural section on *Plate XIV*.

## INSTRUCTOR'S REMARKS

## GEOLOGY MANUAL

### *List of Described Maps Showing the Work of Underground Water*

- |                         |                          |
|-------------------------|--------------------------|
| (1) Cucamonga, Calif.   | (5) Tusayan, Ariz.       |
| (2) Mt. Whitney, Calif. | (6) Disaster, Nev.       |
| (3) Tularosa, N.M.      | (7) Arredondo, Fla.      |
| (4) Echo Cliffs, Ariz.  | (8) Standingstone, Tenn. |

#### SPRINGS:

The first three maps illustrate the different types of springs which are found on bolsons or alluvial fans.

*Cucamonga* (1) is a striking example of an alluvial fan and its associated springs. The surface of the groundwater table, as determined by wells south and southeast of Chino, is at an elevation of seven hundred feet, at Ontario eight hundred feet, at North Ontario nine hundred and fifty feet, and at San Antonio one thousand six hundred feet. Thus the surface of the water table (compare topographic map) is only a few feet beneath the surface south of Chino, two hundred feet deep at Ontario, three hundred feet deep at North Ontario, and three hundred feet deep at San Antonio. This illustrates how the surface topography slopes upward more rapidly than the water table.

*Border springs* are due to the change in gradient at the line between the alluvial slopes and central flat of a desert basin or playa. Ground water is brought to the surface primarily by the change of slope, but the dense silts and clays of the center of the basin tend to act as a dam to prevent further movement down the slope. Thus by their presence they assist the water to rise, and may determine the exact location of certain springs. An example is seen in the springs which form the source of the permanent streams in the extreme southwest corner.

Between Ontario and Pomona the underground waters are brought to the surface, because of an effective obstruction to the sub-surface circulation formed by the impervious beds. The pore spaces below the groundwater table are normally saturated with water, and the base of the major underground water zone is not determined by an impervious layer, but by the closing of open pores and fractures with depth due to pressure, cementation, and other causes. If the irregularities of the rock floor project through the surface of the alluvial plains, the water contained in the alluvium may be forced to the surface. Under these condi-

tions the rock projections act as dams against the regular flow of the ground water, and the resulting springs may be called *rock dam springs*. The best known examples are the *cieneegas* of Southern California. An example is shown west of Cucamonga, where a projection of older cemented alluvium in the Red Hills (elevation 1472 feet) produces East and West Cienegas, and brings the underground water to the surface for two or three miles.

*Mt. Whitney* (2) is intended to illustrate the porous nature of the valley fill, and the imperviousness of the rock basin in which it lies, making ideal conditions for the storage of underground water. The porosity of the valley fill as a whole is estimated at 25%. Owens Valley is a water-tight basin, receiving its supply entirely from precipitation and disposing of it by both ordinary and *vegetal evaporation*. In the valley floor, the depth of groundwater is only a few feet. It becomes progressively greater towards the mountain slopes, and probably lies from 200 to 300 feet beneath the outwash slope at about the 5000-foot contour.

#### RELATION OF RUN-OFF TO RAINFALL<sup>1</sup>

The following data were obtained in an investigation of the surface and underground waters of Owens Valley as a source of water supply for Los Angeles.

The solid granite of the upper mountain slopes, though fractured and disintegrated at the surface, is unfissured beneath and impervious to water. The average slope is 2000 feet per mile, the rainfall is 30 inches; the run-off is 75% and evaporation 25% in the Taboose Mountain section.

The intermediate mountain sides have about the same slope, but are covered with a mantle of porous disintegrated rock and slide material, which merges into the valley fill. The rainfall is 17½ inches, the run-off is 0, the percolation 70%, and evaporation 30% in the Taboose Mountain Section.

The outwash slope has a grade of about 500 feet per mile, and is the desert portion of the surface of the valley fill, extending from the 6500-foot contour to the upper edge of grass and irrigation land in the valley at 3900-4000 feet. The rainfall in the Taboose Mountain section is 7 inches, the run-off is 0, the

<sup>1</sup> The following description was written by Dr. A. F. Buddington.



percolation 16%, and evaporation 84%. The material is porous sand and gravel brought down from the mountain.

The valley floor is almost level, and is underlain by an unknown thickness of clay, sand, and gravel. The upper layers are soil and clay. The rainfall is only 5 inches, the run-off 8%, percolation 16%, and evaporation 76% in the same section as mentioned above. The fact that the run-off here is relatively greater than on the outwash slopes is in part due to the greater imperviousness of the underlying materials, and the equal percentage of percolation in both regions is due in part to the more level slope.

Many springs of the *pocket spring* type are found on the mountain slopes of the east range, and Scotty Spring on the west side near the north edge of sheet is of similar origin. Pockets filled with slide material and alluvium overlie an irregular surface of relatively impervious rock and constitute a reservoir which feeds the springs at their bases.

In the areas previously discussed, although the drainage is distinctly of the interior type, there is usually sufficient excess run-off from the springs on the valley slopes to support a master stream. On *Tularosa* (3) the drainage is entirely interior, with the formation of *ephemeral* lakes or *playas* during the rainy season or during cloudbursts. The streams for the most part lose themselves by percolating into the porous materials of the alluvial slope and join the body of underground water. The water in the valley fill is lost mainly by return to the atmosphere through evaporation. Salt Creek has become a permanent stream by having cut down its channel to the approximate level of the ground water table. The depth to the water table is not more than a few feet at Alkali Flat; about 25 feet at Purday Ranch; and 100 feet at Tularosa Ranch, in the southeast corner of sheet. The surface of the water table is therefore seen to slope less rapidly upward than the land surface.

The springs in the valley are of two kinds. One kind is caused by abrupt irregularities in the land surface whereby the water table is exposed, as in the case of the springs along Salt Creek. The other kind is brought to the surface under *artesian* pressure by openings which go down to the level of groundwater beneath the valley fill. Such are some of the springs on the east side of the "sands."

Most of the valley fill consists of clay or adobe, with inter-

bedded lenses of sand and gravel. The proportion of sand and gravel is greater near the mountains. Flowing wells are found south of Purday Ranch, and the gravel and sand lenses act as aquifers, the clay beds serving as an impervious retaining agent until penetrated by the well.

An interesting feature shown on *Echo Cliffs* (4) is the line of springs along the base of Vermilion Cliffs and Echo Cliffs. The geologic structure favorable for the accumulation of groundwater to feed these springs is as follows: The Navajo sandstone, which forms the surface rock on the plateau to the east and north, has a high porosity, and its surface is so completely covered by wind-scoured depressions and irregularly placed dunes that run-off is almost entirely prevented. The rocks have gentle dips with the result that water falling on the exposed collecting basin is imbibed by rocks of high water-holding capacity and, by the structural arrangement of the sedimentary beds, is directed southward or southwestward to the edge of the cliffs, where it issues at the contact of the porous sandstone and underlying impervious shales. Springs of such an origin are known as *contact springs*. The reservoir for these springs constitutes a *perched water table*, for beneath the impervious layers no water would be found on drilling until the very much deeper surface of the permanent water table were reached.

The mesas and buttes on *Tusayan* (5) embrace a group of lava-capped elevations which rise sheer above the flat-floored washes at their base. The mesa sides are made up of sandstone and shales; their tops are formed by remnants of sheets of lavas, 20 to 100 feet thick.

*Mesas* and *buttes* are typically developed in flat-lying sediments, or lava flows or in interbedded flat-lying sedimentary beds and lava flows. The circulation of the water within the mesas follows a simple plan. The rain percolates into and through the porous and fissured lava, and reaches the intercalated ash beds, only to be arrested by the more impervious sedimentary strata below, along which it passes to the mesa edge. This is clearly shown on the map by the fact that most of the springs are located at reentrants on the contour lines. Such springs, issuing at the contact between pervious and impervious rock layers, are known as contact springs or, in this case, as mesa springs.

The hot springs shown on *Disaster* (6) flow during both sum-



mer and winter, and are probably deep-seated in origin, the water finding its way to the surface along zones of faulting. Such springs are termed *fissure springs*. Occasionally within the Great Basin Province these springs lie in a straight line, in which case their origin is more or less evident.

#### SINK HOLES:

The area represented by *Arredondo* (7) lies within the "sink" (swallow hole) region of northern Florida, characterized by gently rolling, hilly topography.

The district is covered with sands and clays underlain by practically horizontal limestones. The latter are being eroded through solution at a computed rate of about 400 tons per square mile per year, producing, with the aid of some mechanical wash, the sink holes and "prairies" shown on the map. The largest of the basins are as a rule reduced to the level of the underground water table, since solution proceeds more rapidly in the belt of weathering above the zone of saturation than within it. Many of the smaller basins have not reached the permanent water level, and stand at varying heights above it. In such cases the basins may be drained by boring wells to connect with the underground water table.

If the bottom of "swallow holes" become blocked, small lakes or pools come into existence. A striking example is shown in the history of Alachua Sink, about  $4\frac{1}{2}$  miles south of Gainesville on the Southern Railroad. Previous to 1871, the principal stream of this region emptied into a sink or swallow hole in the Alachua Prairie. By the choking of this outlet a lake was formed, which at its greatest extent was 8 miles long and in one place 4 miles wide, and of sufficient depth to permit a number of freight steamers to ply upon it. After existing for about 20 years, the underground passage from the swallow hole was opened again and the lake gradually disappeared.

Because of (i) the relatively flat topography, (ii) the character of the soil, consisting of pervious sandy clays overlying porous limestones, (iii) the widespread vegetation, and (iv) the heavy rainfall (53"), the amount of water absorbed by the rocks is large, and equals about 50% of the rainfall, whereas the direct run-off (not counting addition from the groundwater) is only 3 to 4%. The rate of evaporation is relatively high, about 50% of the rainfall being returned to the atmosphere by evapo-

ration from the surface and soils (20") and to a lesser extent by vegetation (5"-6"). These data illustrate some of the factors affecting the amount of water passing to the underground water reservoir.

Attention is called to the fact that these lakes cannot be due to glaciation as they are south of the limits reached by the continental glacier. They cannot be explained as due to wind scour, as the numerous streams indicate that there is a heavy rainfall. Neither can they be explained as due to the work of the ocean, or rivers, or vulcanism. As far as the map shows, they might be explained as due to the irregular surface of a coastal plain recently uplifted from the sea, but even in this case the relative depths, size, and abundance of the depressions seem out of harmony with such a theory. The true explanation is based on field evidence.

*Standingstone* (8) shows mature drainage in a plateau where the climate is moist and the strata are, at the most, only gently folded. The characteristic digitate type of drainage illustrated here is one which usually develops only in rocks of more or less uniform or homogeneous character. Plutonic igneous rocks, and flat-lying or very gently folded sedimentary beds or volcanics, will usually react to agencies of erosion in just such a roughly uniform manner. An inspection of the geologic map of North America will show that the Standingstone quadrangle lies within the province of the Appalachian plateaus, the whole of which are underlain by sedimentary beds, only gently folded. For similar examples, see Watkins, N.Y., Kaaterskill, N.Y., Elmira, N.Y., and the northwestern portion of the Bristol, Va., sheet. The depressions (sinks without surface outlets) form the special feature of the map. Round Cove, Icy Cove, Big Sink, and Morrison Cove are good examples. Some of the coves have three depression contours, and are therefore more than 200 feet deep, but not as much as 400 feet. The map shows that short creeks flow into many of these coves and disappear, indicating that their waters find an outlet downward through underground courses, perhaps to issue elsewhere in the form of springs. Such features are most common in regions where the underlying rock is limestone, a relatively soluble rock. Many sinks are produced by the collapse of underground caves.

The map also shows many coves with outlets, such as Dyer and Whitaker Coves and Cowan and Madewell Hollows. Some

## GEOLOGY MANUAL

of these may have been developed from depressions without surface outlets. If, for example, the head of the valley just south of Beaver Hill (near the center of the area) worked back to the basin of Sinking Cove, the depression might acquire a surface outlet; or if for any reason the downward outlet in the cove became clogged, as it might by caving, water might collect in the basin and finally overflow. Under such conditions Sinking Cove might be drained north, and would become somewhat like the coves with surface outlets. The subterranean water courses in this region were probably developed in large part before the topography had reached its present maturity, and at a time when the rainfall was less perfectly carried away from the land surface.

### INSTRUCTOR'S REMARKS

## GEOLOGY MANUAL

### LABORATORY EXERCISE ON THE WORK OF UNDERGROUND WATER

#### *List of Undescribed Maps*

Alturas, Calif.

Renault, Ill.-Mo.

Citra, Fla.

Pocahontas, Va.

Diamond Creek, Ariz.

1. Locate and describe all of the features caused by underground water which occur on each of the undescribed maps.
2. Study the demonstration collections and write a concise, illustrated description of the depositional work of underground water.
3. Be sure that you understand all the following terms: depression contour, sink, stalactite, stalagmite, groundwater, solution, cement, concretion, vein, meteoric, run-off, juvenile, vegetal evaporation, groundwater table, border spring, rock dam spring, pocket spring, artesian, contact spring, mesa spring, fissure spring, geyser, tufa, sinter, aquifer.

#### INSTRUCTOR'S REMARKS



1    LABORATORY EXERCISE ON UNDERGROUND WATER

NAME

DIVISION

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2    LABORATORY EXERCISE ON UNDERGROUND WATER

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3    LABORATORY EXERCISE ON UNDERGROUND WATER .

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mere

## INTRODUCTION TO THE STUDY OF MOUNTAIN GLACIATION ON TOPOGRAPHIC MAPS

THE work of mountain glaciers is both constructive and destructive, the former producing some of the most striking land forms shown on topographic maps. The study of mountain glaciation is interesting because:

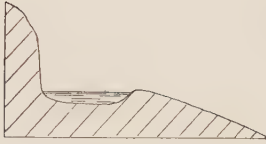
- 1) Several mountain ranges, such as the Alps, Sierras, Himalayas, etc., bear existing glaciers.
- 2) Many high ranges have been recently glaciated.
- 3) Of evidences of climatic changes.
- 4) Of data as to continental glaciation.

### EXISTING GLACIERS:

“Living” or active mountain glaciers have been especially studied in Alaska and the Alps. For a full discussion of the phenomena of mountain glaciation see your lecture notes and text. We shall only review here those details and features which are expressed on topographic maps. A mountain glacier starts in the *névé* region, usually slightly below the top of the mountain and in some sheltered spot, such as a slight depression or irregularity in the hard rock surface which offers a lodgment for the continual accumulation of snow. After the snow bank has reached a certain thickness, it tends to develop an armchair-like basin or cirque. The exact origin of the cirque is not yet definitely known, but it is largely due to the alternate thawing and freezing of the ice in the cracks and fissures of the head wall region, thus tending to sap the sides of the cirque and enlarge its depth and area. Cirques are therefore seen to grow by headward erosion, as also do river valleys. As the snow continues to accumulate in the *névé* region, the lower layers are changed to ice and begin to flow down through the river valley, modifying its shape in a way which will be described later. As the ice flows down the valley, it erodes and carries considerable material on top of it, underneath it, in front of it, and also along its sides. The material on the sides is largely derived from talus and the rock *débris* falling from the valley walls. The material deposited underneath the glacier is called *ground moraine*; that in front of the glacier, *frontal* or *terminal moraine*; and that along the

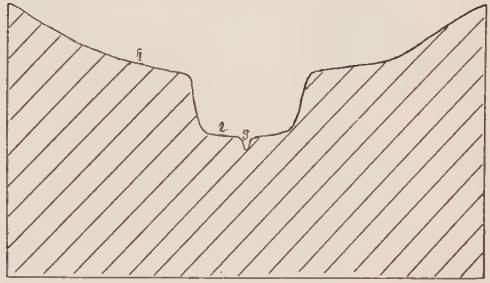


PLATE XV.



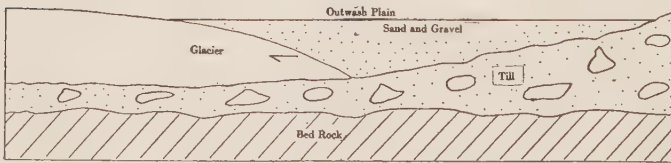
1

Profile of cirque and tarn.



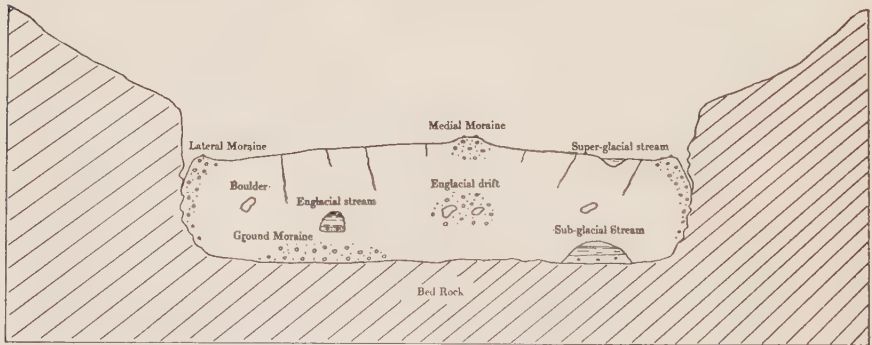
2

Profile of lower portion of U-valley showing its relation to the pre-glacial and post-glacial valleys. (1) alb, or remnant of old river valley. (2) over-deeped U-valley. (3) post-glacial misfit stream valley.



3

Longitudinal profile of valley glacier or main ice stream which has overridden an older glacial till and is now retreating by melting at its frontal margin.



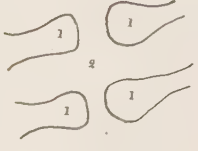
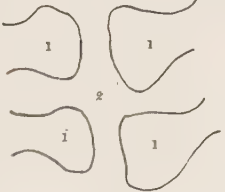
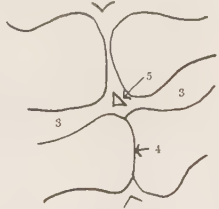
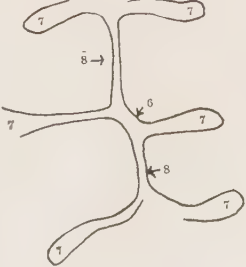
4

Transverse profile of valley portion of mountain glacier which is fed by two smaller mountain glaciers.

After Hobbs.

PLATE XVI.

CYCLE OF CIRQUATION

|                           |                                                                                                                                                                                           |                                                                                              |
|---------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------|
| <p><b>YOUTH</b></p>       | <p><b>GROOVED UPLAND</b> as illustrated by the Big Horn Range. Pre-glacial surface of intercirque area <sup>(2)</sup> bounded by cirques <sup>(1)</sup>.</p> <p>Instructor's remarks:</p> |  <p>1</p>   |
| <p><b>ADOLESCENCE</b></p> | <p><b>EARLY FRETTED UPLAND</b> as illustrated by the Welsh Highland. Pre-glacial surface reduced to smooth and well rounded divides.</p> <p>Instructor's remarks:</p>                     |  <p>2</p>   |
| <p><b>MATURITY</b></p>    | <p><b>FRETTED UPLAND</b> as illustrated by the Alps. Pre-glacial surface reduced to lateral combs (3) and ridges (4) and horn (Matterhorn) (5).</p> <p>Instructor's remarks:</p>          |  <p>3</p>  |
| <p><b>OLD AGE</b></p>     | <p><b>MONUMENTAL UPLAND</b> as illustrated by parts of the Glacier National Park. Development of comb ridges (6) monuments (7) and cols (8).</p> <p>Instructor's remarks:</p>             |  <p>4</p> |

sides, *lateral moraine*. When two glaciers join each other, two of the lateral moraines join to form a *medial moraine*. If a glacier is seen to have two medial moraines, you may be reasonably sure that it is fed by at least three tributary glaciers. A glacier retreats by melting, both at its front and on its surface. As the ice of a retreating (melting) glacier is usually greatly fissured, the surface water rapidly plunges below to form englacial and sub-glacial streams. These streams carry a large amount of cobbles, pebbles, sand, and rock flour, which emerge at the foot of the glacier and sometime form mappable *outwash plains*, deltas, or estuarine deposits. All of the above-mentioned features may be recognized on topographic maps which show the lower portions of large mountain glaciers.

#### GLACIATED MOUNTAINS:

When the glaciers disappear, they leave physiographic evidence of their former existence. The most striking topographic features are *cirques* and U-shaped valleys. The former are armchair- or stadium-like structures, which often contain beautiful little lakes called *tarns* (*Plate XV, fig. 1*). Sometimes the cirques are in tandem, showing that as the climate grew warmer the névé region retreated up the mountain side. U-shaped valleys are the result of the modification of pre-existing river valleys by the valley portion of the glacier. U-shaped valleys can usually be told from river or V-shaped valleys by the fact that the contour lines cross the stream in the form of a U rather than in that of a V. Glaciated or U-shaped valleys are sometimes spoken of as being over-deepened and contain *misfit* streams which could not have developed the valleys in which they flow. Sometimes the streams have been flowing long enough to cut a "young" or V-shaped channel in the glacial U-floor. This is shown by the compound U- and V-contour. A striking result of the deepening of the main U-valley by the ice tongue is the development of *hanging* valleys. So long as the ice remains in the main valley, the tributary valleys or canyons cannot cut below the main ice level. The former level of the ice in the main valley is often beautifully shown by the equal altitudes of the tributary cirques or hanging valleys. It is interesting to note that, unlike the case of normal stream erosion, tributary glacial valleys do not meet the main glacial valley at grade, and that the misfit streams of the former when they reach the edge of the

U-valley often form beautiful waterfalls. The depositional features of glaciated mountains are usually too small to be shown on a small, topographic map.

#### CYCLE OF CIRQUATION:

Because of the features noted above, the erosion cycle of mountain glaciation differs from that of the river or regional cycle. Further, no matter how effective mountain glaciation may have been in producing characteristic topographic features, these features are largely superimposed upon a partially developed river or continental glacial cycle. With the exception of cirques, the valley forms which you will study are glacially modified river valleys and, as has already been pointed out, the glacially modified river valleys may in turn be slightly modified by their misfit streams. Notwithstanding the fact that glacial topography is usually superimposed upon a river or normal regional cycle, and that it also may be subsequently modified by the early stage of a later river cycle, the glacial features are usually so striking and picturesque as to make them readily distinguishable on topographic maps.

#### YOUTH: (*Plate XVI, fig. 1*)

In the youthful stage we have a pre-glacial upland of relatively smooth surface which is grooved by youthful cirques with relatively short but pronounced glacial valleys.

#### MATURITY: (*Plate XVI, fig. 3*)

In the maturer stage of the cycle, the enlargement of the cirques destroys more and more of the inter-cirque, pre-glacial surface until it is reduced to narrow or knife-like ridges called *arêtes* or comb-ridges and cols. The intervening angular mass between the headwalls of three or more cirques becomes the type of pyramidal peak called a *matterhorn*, and is largely responsible for the striking scenery of the Swiss Alps. This stage in the cycle may be called a "Fretted Upland."

#### OLD AGE: (*Plate XVI, fig. 4*) - *more peaks*

The closing stage in the cycle of mountain glaciation is that of a "monumental upland," so well illustrated in the Uinta Range in Utah. The *matterhorn* is reduced, and the *arêtes* and cols have been lowered and rounded off, with the result that the terminal portion of the Lateral Combs (monuments) become the mountainous features of the landscape.

*List of Described Maps Showing Mountain Glaciation*

- |                                                                                           |                                                                                                              |
|-------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------|
| (1) Rainier National Park,<br>Wash. ( <i>See description</i><br><i>on back of sheet</i> ) | (2) Chief Mountain, Mont.<br>(3) Mt. Lyell, Calif.<br>(4) Mt. Whitney, Calif.<br>(5) Gilbert Peak, Utah-Wyo. |
|-------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------|

## ACTIVE GLACIERS:

Examples of existing glaciers and their deposits are well shown on *Rainier* (1). For a description of the glacial features exhibited, read the description on the back of the sheet, especially the paragraphs headed *Glacier System of Mount Rainier* and *Sculpturing by the Ice*. Note especially the depositional features such as: terminal, lateral, and medial moraines. What is the evidence that some of the glaciers have retreated? Waning and youthful glaciers (glacierets) are shown on *Chief Mountain* (2).

## GLACIATED MOUNTAINS:

The *Chief Mountain* map (2) illustrates mountain glaciation better than any other ever issued by the United States Geological Survey. Further, the relation of the R.F. to the contour interval has been so nicely determined as to bring out the topographic features in a very striking manner. The topography becomes as nearly self-evident as it is possible to make it by using contour lines. Provided the region has been accurately surveyed, it is doubtful if any other method of mapping could present as accurate and artistic a picture of the area as this method does.

The mountains of western Montana contain a number of more or less inactive glaciers of the type represented on this sheet. As a rule they are small and rarely extend below the snow line into the larger valleys. The factors affecting the origin and growth of mountain glaciers are (a) original topography, (b) exposure to the sun, (c) direction of prevailing winds, (d) altitude, and (e) amount of precipitation. Some of these factors may be determined by a close inspection of the topographic map. The lowest glaciers in this area are those north of Mt. Wilbur (north central area of the map) at approximately 6,000 feet altitude. Most of the present glaciers are at somewhat higher altitudes. This indicates that the general snow line for the region is at least 6,000 feet at the present time (under the present conditions). If the climate of this region were to become



much warmer or drier, or both, these small glaciers would disappear, leaving as evidence of their former existence the amphitheaters or armchair-like basins which are called *cirques*. As a matter of fact, in former times the snow line was several thousand feet lower than at present, as is shown by the many well-defined cirques at lower altitudes, so beautifully illustrated by this map. If the student makes a traverse from the top of an existing glacier downward into the main valley, he will usually encounter a step-like series of cirques, one below the other, until he arrives at a relatively broad, *U-shaped* valley which, in its lower levels, may become V-shaped. Such phenomena are good evidence of a more or less successive upward recession of the snow line, probably brought about largely by an amelioration of climate. Notice the valley that heads between Mount Brown and Edwards Mountain, near the southwest corner of the area. The lower two and one-half miles is V-shaped and was probably never glaciated, while the upper mile or more is deep and steep-sided, and its bottom is narrow but U-shaped. The peculiar head of this valley comprises two cirques, one above the other.

There are two principal types of lakes shown on this map. The little circular lakes which nestle in the rock bowls of the cirques are called *tarns*. Where there is a step-like procession of cirques, there is also usually a pearl-like series of lakes or tarns. The larger and longer lakes which are located in some of the U-shaped valleys are called *finger lakes*. The map does not always show whether these finger lakes lie in rock bowls or troughs which have been gouged out by the former movement of the ice through these old river valleys, or whether they have been formed by the damming of the lower ends of the U-shaped valleys by glacial drift.

There are three important types of glacial lakes, the two already alluded to, and also pit lakes or kettle holes. The latter are only found in regions characterized by ground moraines, and their origin is quite different from that of the finger lakes and tarns. Tarns are found only in regions of mountain glaciation; finger lakes in both regions of mountain glaciation and continental glaciation; and pit lakes or kettle holes usually only in regions of continental glaciation, associated with terminal or ground moraines.

The western portion of map *Mt. Whitney* (4) shows numerous cirques and U-valleys. Why is most of the evidence of gla-



ciation west of the county boundary line? This map is especially interesting in that it shows mountain glaciation, river and regional erosion, deposition, and evidences of underground water. *This is a type of map which you may get on your final examination. Practise on it now.*

#### CYCLE OF GLACIATION:

Maps (2), (3), and (4) all show the mature stage in the cycle of circulation. *Gilbert Park* (5) illustrates a region in which the mountain glaciation was developed to the old age stage of cirquation before the disappearance of the ice. The general aspect of the region is similar to the effect produced by drawing one's fingers through soft clay. The U-valleys are well developed and are "headed" by more or less confluent amphitheaters. This is particularly well illustrated in the region of the headwaters of the Uinta River. Notice that the cirques (amphitheaters) are from three to four times longer than wide, and the side walls or ridges are more nearly parallel than in the case of the youthful cirques previously discussed. This is well shown by the cirque (amphitheater) tributary to the valley of the Uinta and just north of latitude  $40^{\circ} 40'$ . The group of cirques directly south of the Wasatch National Forest illustrates, very well, the stage of mountain glaciation called "Monumental Upland" or Old Age (see *Plate XVI*). Wilson Peak is a rather poorly developed *matterhorn* and Red Castle is a typical *Monument*. There are several other well developed monuments in this region which have not been named on the map. See if you can point them out to your instructor. Both the *comb ridges* and *cols* are also well shown.

#### INSTRUCTOR'S REMARKS

comb ridge  
col  
monument

## GEOLOGY MANUAL

### LABORATORY EXERCISE ON MOUNTAIN GLACIATION

#### List of Undescribed Maps

Hyden

Valdez, Alaska  
Nyack, Mont.

Hayden Peak, Utah-Wyo.

1. Locate, name, and describe all the glacial phenomena illustrated by the undescribed maps.

(or)

2. State the glacial phenomena which each map best illustrates.

3. State and describe the stage in the cycle of cirqueation which each map illustrates.

4. Discuss present and earlier "snow line" levels as shown by cirqueation on each of the undescribed maps.

NOTE: Be sure that you understand the following terms: Glacier, medial moraine, lateral moraine, terminal moraine, outwash plain and delta, nunatak, finger lake, cirque, tarn, U-valley, hanging valley, monument, col, névé, arête, headwall, matterhorn, misfit stream, alb.

#### INSTRUCTOR'S REMARKS

snow line - that line above which all precipitation is in the form of snow  
névé - granular snow, like the crust formed on the surface of the snow after a rain.

tarn - a lake formed in the bottom of a cirque

cirque - an amphitheater-like excavation caused by the action of the plucking of a glacier

finger lake - a lake which fills the bed of a U-shaped valley.

misfit stream - a stream flowing through a U-shaped valley.

alb - what is left of the old river valley

col - any pass developed in the mountains. - usually in the center of a comb ridge, formed by the eating in of two cirques.

comb ridge - a saw-tooth ridge formed by the interpenetration of two cirques.

monument - a high projection at the end of a comb ridge.

nunatak - any point projecting up above the ice of a glacier.

outwash plain - the plain formed by material carried down + deposited out in front of a glacier.

matterhorn - the erosional residue left at a point near the head of three or more cirques



## 2 LABORATORY EXERCISE ON CONTINENTAL GLACIATION

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### 3 LABORATORY EXERCISE ON MOUNTAIN GLACIATION

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DATE





## INTRODUCTION TO THE STUDY OF CONTINENTAL GLACIATION ON TOPOGRAPHIC MAPS

ALL geologists now believe that large areas have been covered by continental glaciers. Unfortunately the present ice fields, such as those covering Greenland and the Antarctic have, so far, yielded little information as to the work of continental ice sheets. Most of our speculations and theories regarding topographic features within recently glaciated regions have been gradually evolved from the study of mountain glaciers. In fact, the glaciation of a large part of northern North America was postulated by Louis Agassiz from his previous studies in the Swiss Alps. The more recent study of the piedmont glaciers of Alaska has helped us to understand the work of large ice sheets. For a general statement as to the causes and effects of continental glaciation, see your lecture notes and text.

Although several topographic features are common to both "mountain" and "continental" regions (in fact, a sufficient number to intimate the work of ice in both cases), there are striking features which are highly characteristic of each. Several of the topographic forms, the result of continental glaciation, still await a fuller explanation as to their origins.

Continental glaciers are "born" and develop in a different manner from mountain glaciers. The origin of the ice sheet is due to the constant accumulation of snow in the high latitudes, with a consequent piling up of snow at the center and a flowing out of ice at the periphery of the mass, due to the increasing weight at the center. Thus the ice streams or sheets did not necessarily originate in a highly elevated or mountainous area, and cirques are therefore absent in regions of continental glaciation. Not only did the central Canadian ice sheet originate in relatively low ground, but it probably moved uphill for some distance into the United States. The most active period of mountain glaciation in North America, previously studied, is approximately of the same age (Pleistocene) as that of the great pre-existing ice sheets to the north, and is often spoken of as "sympathetic" mountain glaciation.

The work of the continental ice sheet may be classified as

either constructive or destructive. Both destructive and constructive topographic features may be observed on topographic maps. Further, certain pre-glacial and post-glacial modifications are well illustrated and present interesting problems in the derangement of streams. The student must remember, however, that many of the constructional features of continental glaciation, as shown on topographic maps, may be readily confused with phenomena already discussed in the previous exercises. As pointed out in the "Introduction to the Study of Topographic Maps," you must constantly bear in mind all the possible interpretations of the land forms illustrated by the particular map which you are studying. The proper determination will be largely governed by your general knowledge of erosional processes and the topographic features which they produce. This is the last exercise on the general subject of sub-aerial denudation; so that with the knowledge which you now have of physiographic processes, you are expected to exercise better judgment and power of discrimination in the interpretation of topographic maps than heretofore.

#### EROSION FEATURES:

An ice sheet may advance over either a non-glaciated or glaciated area; the resultant topography will vary in each case. If a thick ice sheet spreads over an unglaciated region, it will tend to modify the pre-existing topography and obliterate many of its earlier features. The hills will tend to become *rock drumlins* or *roches moutonnées* (sheep backs), and the normal V-shaped valleys, U-valleys, which when filled with water in turn become finger lakes. In both Europe and North America ice sheets have over-ridden older glacial deposits of tills, sands, and clays. In this case the weight and movement of the ice has, in certain areas, molded the unconsolidated and more or less plastic till into true *drumlins*.

#### DEPOSITIONAL FEATURES:

The depositional work of a glacier is twofold. A large amount of fragmental material is carried and pushed by the ice sheet. This material is called *unstratified drift*, and remains in the form of *terminal moraines*, *ground moraines*, *boulder trains*, or *erratics*. Only the morainal material forms deposits of sufficient size to be shown on topographic maps. The unstratified drift or *till* is often mixed with, or merges into, the stratified drift of the

## GEOLOGY MANUAL

outwash plain, glacial lake deposits, deltas, etc., so characteristic of parts of the New England states. With the stratified drift are associated *eskers* or *osars*, which are old glacial stream deposits, and *kettle holes* or depressions in the *outwash plains* which once contained ice blocks left by the retreating glacier. The great continental glaciers did not, in general, reach south of the Missouri or Ohio Rivers. Consequently, topographic features south of these rivers should not be ascribed to the effects of glaciation. North of these rivers, however, we have many topographic types resulting from continental glaciation. One such type is the lake region of Michigan, Wisconsin, and Minnesota and the Laurentian Plateau of Canada. There are 15,000 lakes in Minnesota and Michigan, most of which occupy the depressions in the irregular surface of the ground moraine, terminal moraines, or outwash plains, and are largely responsible for the hummocky or "*kame*" topography. The abundant lakes of New England and the Adirondack Mountains result, in the main, from the *disturbed* drainage in glacial deposits.

### INSTRUCTOR'S REMARKS

## GEOLOGY MANUAL

### List of Described Maps

- |                     |                        |
|---------------------|------------------------|
| (1) Watkins, N.Y.   | (5) Minneapolis, Minn. |
| (2) Boothbay, Me.   | (6) Pingree, N.D.      |
| (3) Weedsport, N.Y. | (7) Port Leyden, N.Y.  |
| (4) Islip, N.Y.     | (8) Elmira, N.Y.       |

### EROSION :

The first map illustrates both glacial and post-glacial erosion. The narrow gorges such as Excelsior Glen, Havana Glen, and Watkins Glen, are extremely youthful types and must have been cut in the rock since the recession of the glaciers from this region. Texas Hollow appears to be an old *U-shaped* valley with *misfit streams* flowing in opposite directions. In time the headwaters of one creek will probably tap the headwaters of the other, producing an example of post-glacial piracy. Seneca Lake lies in a rock basin or old U-shaped valley which has been deepened locally by glacial erosion, and is one of the many lakes of this region known as *finger lakes*.

*Boothbay* (2) illustrates a number of roughly cigar-shaped, rocky hills, such as Cushman Hill, Barter Island, etc., the longer axes of which have a north and south trend. Hills of this type are probably *rock drumlins*.

### DEPOSITION :

*Weedsport* (3) portrays a special phase of *ground-moraine* topography, where the old morainal material left by a previous ice advance has been over-ridden by a later ice advance. The most important features are the remarkable elliptical hills of drift known as *drumlins*. Note that the drumlins are elongate in the direction of the ice movement. Drumlins are rarely found alone but usually occur in large numbers over wide areas. True drumlins (formed of till) are usually much more perfectly formed than rock drumlins, and are the work of the ice alone.

On *Islip* (4) the dominant features are two belts of very uneven, rough and hummocky topography with a maze of numerous pits and flooded depressions having no outlet. These belts extend in an east-west direction, and each is fronted on the south by a gentle, relatively flat, sloping plain; the northern plain, between the two rough belts, being the less well developed and of varying width. The junction of an approximately



east-west belt of such low, rough topography with a gently sloping plain to the south, located within the area formerly covered by the continental glacier, suggests successive *terminal moraines* (*recessional moraines*) each with its corresponding outwash-plain resulting from successive, long-period stops in the more normal gradual retreat of the ice front towards the north. This interpretation is confirmed by the field evidence, for the outwash plain is composed of stratified sands and sandy loams, and the terminal moraine is composed of till and associated water-worked sands and gravels with some typically glaciated or striated boulders and cobbles. Lake Ronkonkoma is probably a kettle hole.

*Minneapolis* (5) illustrates a portion of the lake region of Minnesota, and shows a type of topography which is characteristic of thousands of square miles in this region. The country is rough without great relief—that is, a region where elevations and depressions lie close together, though the hills are not very high nor the depressions very deep. Many of the depressions have no outlets and contain lakes and ponds. There are also great areas of marsh. This topography is the result of uneven deposition of drift or till by the retreating continental ice sheet. A large part of the marsh and swamp land is covered with peat, generally 5 to 10 feet thick.

same  
topograp

Many of the wagon roads are crooked, but the railways are straight. Although the railways do not traverse the roughest parts of the area, their construction suggests that the hills are composed of material easy to remove, whereas the wagon roads, which are built with less regard to grade, go round or over the hills by the laziest routes. The drainage or stream pattern of this area is “aimless,” characteristic of many regions that have been recently glaciated.

The saucer lakes along the flood plain of the Minnesota River have been formed in post-glacial time, and are due to the building of natural levees by the river which prevents the return of the flood waters to the main channel.

Many swamps, especially those traversed by creeks, are surrounded by cut banks, beaches, or ice ramparts, showing that they are the sites of former lakes. Some of these swamps appear to be small lakes that have been overgrown by peat bogs. Others, such as those along the Minnesota River, are due to proximity



to ground-water level and poor drainage. The hills behind the ponds are probably kames.

#### DERANGED DRAINAGE:

*Pingree* (6) lies within the glaciated area. Note that the string of lakes lies along a line of depression, and that the valley of James River is narrow, steep-sided, and youthful. Probably this belt of lakes represents the course of a pre-glacial valley, partly filled at intervals by drift, and the present valley of James River is post-glacial.

*Port Leyden* (7) is an excellent example of a *hanging delta*. It will be noticed that the Black River flows north. During the retreat of the continental glacier, the ice front at one time stood across the Black River at a point north of this sheet, sending a long narrow tongue down the immediate valley of the river itself. The ice therefore acted as a dam, and caused the formation of a temporary lake extending up the Black River valley far to the south of this area. The streams flowing from the Adirondack Mountains on the east built out a delta into this lake as far as the ice tongue which occupied the west side of the valley. With the retreat of the ice, the lake was drained and the delta left hanging on the side of the mountains. The great level area on the east side of the river is the surface of this delta. The depressions are probably due to slumping in of the sands over the sites of buried ice blocks or bergs after they had melted. Streams are now at work eating their way back into the steep front of the delta. The delta does not show on the west side of the river, indicating that a tongue of ice occupied this site at the time the lake existed.

*Elmira* (8) illustrates *deranged* drainage. The significant points in this area are (I) the wide valley between Big Flats and Horseheads, not occupied continuously by the stream; (II) the large valley between Horseheads and Elmira, occupied by a relatively small stream; and (III) the much narrower valley of Chemung River, occupied by a large stream. These features indicate that the drainage of the region has been deranged. The history of this region has been interpreted as follows: The area about Horseheads was notably aggraded by the deposition of stratified drift, from the north; in the form of a *valley train* or outwash plain, the surface being built up so that the drainage from the west found an outlet along the course of a tribu-

## *GEOLOGY MANUAL*

tary valley between Big Flats and Elmira, lower than by the former route through the main valley by way of Horseheads and Elmira Heights. The filling by drift near Horseheads, therefore, diverted the main stream from its large valley; but Singing Creek, coming out from the mountains, found its way across the old valley flat to the Chemung below.

### INSTRUCTOR'S REMARKS

## GEOLOGY MANUAL

### LABORATORY EXERCISE ON CONTINENTAL GLACIATION

#### List of Undescribed Maps

Deerwood, Minn.

Whitewater, Wis.

Skaneateles, N.Y.

Sodus Bay, N.Y.

Clyde, N.Y.

Passadumkeag, Me.

1. Name, locate and describe the glacial phenomena shown on each of the undescribed maps, and state which glacial phenomena each sheet best illustrates.
2. Study the exhibition collections and:
  - a) Describe the specimens illustrating the character of the material forming kames, till, outwash plain.
  - b) Describe and sketch a glaciated pebble and a portion of the glaciated bed rock.
3. Be sure that you understand the following terms: Esker or osar, terminal moraine, ground moraine, outwash plain, ~~hanging delta~~, aimless drainage, misfit stream, finger lake, U-valley, ~~deranged drainage~~, drumlin, glacial lake terrace, kame, pit lake or kettle hole, ~~roches moutonnées~~, drift, till, ~~boulder train~~, valley train, varve.

#### INSTRUCTOR'S REMARKS

drumlin - an elliptical hill of unstratified drift, moulded by a glacier  
roches moutonnées - a planed surface of a rock mound, smoothed off by glacial action.

boulder train - a series of boulders dropped by a glacier

till - unstratified drift of a glacier.

esker - stratified drift deposited in a long ridge by a glacial stream.

kame - (depositional) <sup>short ridges of stratified drift and gravel - heaped up by</sup> subglacial streams as they escape from the margin of the ice.

valley train - debris carried out by glacial streams and deposited at the foot of the glaciers in a valley.

aimless drainage streams that wander about - caused by unsystematic arrangement of drainage lands in a region of hummocky topography.

deranged drainage - preglacial drainage changed; streams now follow new valleys - the post-glacial system.

# 1 LABORATORY EXERCISE ON CONTINENTAL GLACIATION

NAME

DIVISION

DATE

finger lake -

hanging delta -

varve { 

double band which represents seasonal deposition in a glacial lake at the end of a glacier.

glacial lake terrace -

non-glaciated region

remnants of plains high on hills

completely drained (arborescent)

exposed rock decomposed, disintegrated,  
to considerable depth, soil is residual,

glaciated

constructional

remnants of plains on lower hills

rounded shoulders of rock

some undrained portions

aimless drainage

no decomposed rock in place

just hard surface

all kinds of rocks - lavas



3 LABORATORY EXERCISE ON CONTINENTAL GLACIATION

NAME

DIVISION

DATE





## INTRODUCTION TO THE STUDY OF SHORE LINES ON TOPOGRAPHIC MAPS

THE work of waves and currents may be shown either on lake or on sea shores. The maps which you will study illustrate portions of the Pacific coast, Atlantic coast, and the shores of the Great Lakes. The work of the waves may be either constructive or destructive. Certain coasts or shore lines may be particularly characterized by either one or the other of the aforementioned processes, but most shore lines show evidences of both. The relative importance of the two processes will be discussed under the Marine Cycle of Denudation. For a full discussion of the subject, see your text and lecture notes.

### EROSION:

The power of the waves to erode a shore line is increased or decreased by the raising or lowering of the general water level. If the water level remains the same, the waves will carry on active erosion and in time produce a broad wave-cut platform, or even, in the case of a coast line, a marine peneplain. If the water level is lowered, the shore line retreats and the waves and currents are forced to rework old deposits. If the water level rises, the shore line may be drowned so rapidly that the work of the waves may be relatively insignificant. With these facts in mind, we should expect to find evidence of active shore line erosion going on in regions where the coast line is relatively stable or where it is sinking slowly enough to allow the waves time to act. Of course the cutting power of the waves will also be affected by the degree of consolidation or hardness of the rocks which form the shore line. Shore lines, other than coastal plains which are undergoing active erosion, should show relatively narrow beaches and usually well defined cliffs with few or no depositional features. If the map has submarine contours, these will portray the area comprising the *wave-cut terrace* and *wave-built terrace* which is called the *marine abrasion platform*. The minor features characteristic of a shore line which is being actively eroded are usually too small to be shown on topographic maps, with the exception of offshore islands or stacks which were once connected with the mainland. As a rule

# PLATE XVII.

## CRITERIA FOR THE DETERMINATION OF STAGE IN THE CYCLE OF MARINE EROSION (SUBMERGENCE)

|             | DESCRIPTION                                                                                                                                                                                                                                                                          | PROFILE                                                                                                                                                            |
|-------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| YOUTH       | <p>Irregular coast line with drowned river valleys and points or headlands which are beginning to be cliffed. Clified islands off shore. Beaches narrow, and few or no depositional features.</p> <p>Instructor's remarks:</p>                                                       | <p>(NOTE. The abrasion platforms are supposed to slope very gently seaward.)</p>  |
| ADOLESCENCE | <p>Irregular coast line. Headlands and outlying islands well cliffed. Maximum variety of deposition features such as beaches, bars, spits, deltas, tombolos, etc.</p> <p>Instructor's remarks:</p>                                                                                   |                                                                                   |
| MATURITY    | <p>Well defined headlands. Smaller outlying islands have disappeared. Straight coast line the result of the tying together of the headlands by barrier beaches which have changed the bays into lagoons. Lagoons may be partially filled by deltas.</p> <p>Instructor's remarks:</p> |                                                                                   |
| OLD AGE     | <p>Straight, well cliffed shore line. Barrier beaches and lagoons have disappeared. Narrow beaches covered at high tide. Little or no evidence of deposition.</p> <p>Instructor's remarks:</p>                                                                                       |                                                                                   |

an erosional shore line is somewhat irregular, with numerous points or cliffed headlands. The depth of the reentrants or bays will vary according to the general structure of the region, and also as to whether or not the shore line is being submerged.

#### DEPOSITION:

The work of the waves, and the action and interaction of currents, will, if the water is shallow and there is sufficient detritus, build numerous beaches, bars, spits, and capes or forelands. The classification, significance, and origin of these types of shore line phenomena are discussed in connection with the described maps. For a full discussion of the depositional work of the waves, see your lecture notes and text.

#### MARINE CYCLE:

The coast line passes through the stages of youth, maturity, and old age. The cycle of a drowned (submerged) or sinking coast line will exhibit somewhat different phenomena from that of a rising (emergent) coast line. This is particularly true of the youthful and mature stages. In both the submergent and emergent cycles the late mature and old age stages will show relatively straight coast lines with few points or bays. Most of the world's shore lines are of the emergent or submergent type, but many are either neutral or compound; that is, "characterized by phenomena normally characteristic of at least two of the preceding classes" (Johnson). We shall take as an example of the marine cycle the submerged coast line, not only because it is the one which is the most striking and therefore the easiest to illustrate, but also because it seems to contrast the drowned river valley (*Ria*) and drowned U-valley (*Fiord and Fiard*) coast lines which afford some of the principal harbors of the world. The table, page 130, gives the criteria for distinguishing the stage of the marine cycle of a submerged coast line.

#### EMERGENCE:

Whether or not the waves are able to cut marine peneplains, there is no reason to doubt that wave erosion is producing at the present time, and has produced in the past, well defined abrasion platforms. The width and lineal extent of such platforms will depend largely upon the stability of the water level. Thus a spasmodic emergence either of marine coast lines or of lake shore lines may be evidenced by a step-like series of plat-

## *GEOLOGY MANUAL*

forms or benches. (These benches may be either cut in the hard rock or built out of clastic material.) The student must appreciate that the emergence of a shore line or coast line may result either from an absolute lowering of the water level or from an uplift of the coast relative to general water level. In the case of marine coast lines the ocean is our datum plane, and we assume that the continents are uplifted or depressed relative to the ocean basins.

### INSTRUCTOR'S REMARKS

## GEOLOGY MANUAL

### *List of Described Maps Showing Shore Line Features*

- |                                 |                         |
|---------------------------------|-------------------------|
| (1) Tamalpais, Calif.           | (5) Provincetown, Mass. |
| (2) Drum Point, Md.             | (6) Tolchester, Md.     |
| (3) Islip, N.Y.                 | (7) Boothbay, Me.       |
| (4) Martha's Vineyard,<br>Mass. | (8) Euclid, Ohio        |
|                                 | (9) Oceanside, Calif.   |

#### EROSION :

*Tamalpais* (1) shows a coast line which is undergoing both erosion and deposition. The erosional features are the steep cliffs along parts of the coast, and the jagged outline of the coast as a whole, except for Bolinas Bay.

#### DEPOSITION :

*Drum Point* (2) illustrates a highly irregular coast line (described later) and several typical depositional features, such as bars and spits. Cove Point, Cedar Point, Drum Point, and Sandy Point are excellent examples of *cusate forelands*. It is frequently impossible to determine the precise manner in which a cusate foreland may have originated. They are largely depositional, not erosional, shore line features, and are due to the combined action of waves and currents.

*Cusate bars* may originate in the following ways:

- (1) A bar which has advanced some distance into the open water may become a hooked spit, its distal end finally connecting with the shore.
- (2) Spits growing towards each other may join to form a cusate bar.
- (3) If an island, connected to the shore by a double tombolo, is destroyed by wave erosion, the remaining Y-tombolo may become a cusate bar.

Cusate bars and forelands often enclose lagoons such as those at Cedar Point, Cove Point, Drum Point, etc. The cusate bar may have only a temporary or subaqueous connection with the mainland, as at Sandy Point. Often cusate bars and forelands are breached at or near the apex by combined action of rivers and tidal currents. Point Patience is a good example of a *hooked spit*. There are several *baymouth bars* west of Fishing Point. Often the direction of the *long-shore drift* or the relative strengths of the ingoing and outgoing tides is shown by the direction in which the bars or spits are curved. Note how the



terminations of Cove Point and Point Patience are turned towards the outlet. This is because the ebb current is stronger than the flood current, due to the effect of the out-flowing fresh waters brought in by the rivers.

*Islip* (3) illustrates a number of depositional features. Off the south shore, separated from the mainland by long narrow lagoons, there are two *barrier beaches*, Fire Island and Oak Island. The bulk of the material of each barrier beach has been scoured from the sea bottom and built up by the waves. The work of the waves is aided by the wind which raises the sand above the level of the highest storm waves. The *lagoons* behind the beaches are gradually being filled by material brought in by tidal currents and rivers, and the growth of sea weeds. Sand is also blown from the beaches into the lagoon and helps to fill it up.

*Tidal deltas* are often built in towards the land by currents of relatively high velocity which rush through the inlets between the beaches and then split into numerous distributary channels with a consequent decrease in their velocity, and the deposition of a portion of their load. A true tidal delta is largely submerged and can only be told by submarine contours or soundings. It usually consists of two parts; the larger, facing landward, is the result of deposition in the lagoon by incoming currents; the smaller, facing the open ocean, is formed by the outflowing currents and may be modified by the "longshore" drift or the attack of the waves. The salt marshes in the vicinity of Zach's Inlet (west end of barrier beach) may be of this origin. The material partially filling Stony Brook Harbor in Smithtown Bay on the north shore also has the appearance of a tidal delta. Lloyd Point, at the extreme northwest, is a *cusplate bar* formed as the result of two bars being built towards each other by currents. Lloyd Beach is a bar built by the waves and currents which has tied the former island of Lloyd Neck to the West Neck. Eaton Neck is another *land-tied* island. *Bay-bars* are numerous along the shore. A *bayhead bar* is shown at the head of Cold Spring Harbor and *baymouth bars* at the mouth of Sunken Meadow, Nissequogue River, Port Jefferson Harbor, etc. *Sand spits* are shown at East Fort Point and West Beach. Wave erosion is suggested by the bluff faces along Smithtown Bay, and the materials which form the beaches in the vicinity have probably been derived therefrom.

*Martha's Vineyard* (4) illustrates a straight coast line, largely the result of deposition. Along the shore line many lagoons or salt ponds are seen, which have been closed in through the building of bay bars by wave and longshore currents. Little drainage enters these salt ponds. The only permanent stream is that entering Tisbury Great Pond, and the inflowing water seems to be sufficient here to keep an outlet open across the beach. Bars appear to be in the process of development south of Katama Bay, and may in time connect with each other unless the tidal flow between Edgartown Harbor and Katama Bay is sufficiently strong to keep the passage open. The relatively greater force of the inland tidal currents is shown by the inward curve of the bars. This map illustrates clearly the effect of coastal deposition in simplifying a shore line. The marked irregularity of the coast line before the construction of the bars may be easily seen. Compare this area with that of Islip, New York.

The rough hilly topography of Cape Cod, *Provincetown* (5) represents part of a terminal moraine. The cliffs southeast of Highland Life Saving Station are due to wave erosion; whereas from here northwest, the coast line has been the site of deposition. The interaction of various currents has built a *hooked spit* from Race Point southeast.

The western portion of Cape Cod was probably originally an island, which has been tied to the mainland by bars which enclose Pilgrim Lake and Salt Meadow. The long narrow ridges lying north of the rough hilly topography of the western portion, and south of the relatively flat beach of deposition might be interpreted as sand dune ridges.

#### SUBMERGENCE:

As has already been described, *Drum Point* (2) illustrates a highly irregular coastal plain, the shores of which show several typical depositional features. As a rule tidal currents are not sufficiently powerful to enlarge reentrants in the shore line, and it is hardly conceivable that the ebb and flow of the tides could have produced the finger-like series of bays shown on this sheet; moreover, wave erosion tends to obliterate the larger irregularities of a coast line and not to make them. It seems probable, therefore, that these finger-like bays are drowned river valleys, and indicate a negative movement or sinking of the strand line. This type of coastal pattern is called a *Ria* shore line, and is considered to be good evidence of submergence of the coastal plain.

Another example of Ria coast line is shown on *Tolchester* (6). Chesapeake Bay itself is a river valley that has been drowned, and in this process the lower end of every tributary was drowned also. This is the fundamental element in explanation of the deeply embayed coast line shown on this map. Similar phenomena are present along much of the coast between New York and Florida. This does not preclude the possibility, however, that movements of elevation may have taken place subsequently, but such elevation could not possibly have counterbalanced the subsidence.

*Boothbay* (7) illustrates a submerged coast line within the glaciated area of North America. The area is characterized by long, narrow bays or inlets more or less parallel to elongated hills which are oriented roughly north and south. This type of topography is one which is commonly found in a region composed of gneisses and schists and which has reached a stage of maturity through combined river and glacial erosion. Similar topography may result from similar erosional processes in a region of flat-lying sedimentary beds. The elliptical character of the hills, however, oriented as they are with a marked trend, is quite characteristic of a country underlain by highly metamorphosed rocks, the longer axes of the hills being parallel to the foliation (see also Stamford, Conn.). A geologic map would, however, be necessary to make certain of the facts outlined above.

Though weathering and river erosion have probably been the major factors in the development of the topography, glaciation and perhaps change of land level with respect to the sea have cooperated to give the present coast line its "drowned" appearance. The long narrow arms of the sea on the *Boothbay* sheet, with steeply sloping, more or less parallel walls, are in sharp contrast to the funnel-shaped bays bordered by low-lying lands on the *Tolchester, Md.*, sheet. Thus it may be said that the shore line and associated features on the *Boothbay* sheet are particularly characteristic of glaciated regions. In a mountainous or high plateau region, such as Norway or Alaska, such bays are called fiords. In these regions the bays are clearly former river valleys modified and deepened by glacial action and invaded by the sea after the retreat of the ice. The sea may have invaded the land either because the glaciers eroded the valleys below sea level or because the land sank relative to sea level after the ice melted out of the valleys. This question has not yet

been definitely settled. The numerous islands, likewise, may in part have resulted from the sinking of the land, and in part from the ice having cut down former saddles.

The student must not infer from his study of the Boothbay quadrangle alone that the neighboring areas are identical. There is considerable evidence that parts of the New England coast have risen since the glacial period, as is suggested by raised cliffs, beaches, etc. The Boothbay shore line is certainly "fiord-like" even if the bays and inlets may not be considered true fiords. It has been suggested that bays of this type be called *fiards*.

#### CYCLE:

Sheet (1) may illustrate a youthful shore line of emergence, and sheet (2) a shore line of submergence which is in the adolescent stage. It is in the late youthful stage of submergence that the maximum number of depositional features are usually found associated with a well defined Ria coast line. In a still later stage of development we should expect to find a straighter coast line, first with shallower bays and baymouth bars (sheets 3 and 4), finally with no bays at all. (The evolution of a shore line of submergence is somewhat different from that of a shore line of emergence.) Compare the Drum Point quadrangle with the Islip quadrangle.

#### EMERGENCE:

The coastal terraces, stair-like in character, constitute the special feature of *Oceanside* (9). There is a pronounced *terrace* at an elevation of 80 to 100 feet, and others are present at higher levels. Through these terraces the older streams have cut narrow valleys. This is especially well illustrated along the San Luis Rey Valley, shown at the top of the map, where the wide, marshy, bay-like old valley above is continued by a narrow, steep-sided valley of youthful aspect below. The old valley was probably cut at a time when the land stood higher than now, relative to sea level. Later the land sank, and the lower ends of the valleys were drowned and converted into bays. While they were in this condition, the mouths of the bays were obstructed by bars deposited by shore currents. The lagoons behind the bars were then partly silted up. When the land was again uplifted, the drainage discharged across the bars, cutting narrow valleys through them and through the deposits behind them. Subsequently, the land may have sunk a little, drowning the valleys



which are now nearly silted up. This type of coast line may be spoken of as *compound*.

*Tamalpais* (1) shows well defined *coastal terraces* west of Bolinas Bay. There seems to be a broad terrace at an elevation of slightly less than 200 feet, and a sloping terrace running up to 300 feet where a higher cliff appears. Suggestions of a terrace at similar levels are found elsewhere, though in no other place are they so pronounced.

At the edge of Lake Erie, *Euclid* (8), is a beach behind which a bluff rises about 30 feet above lake level. Further inland there is a broad bench or terrace about two miles wide, with a gentle slope of about 35 feet to the mile (600'-670'). Still further inland is an escarpment over one hundred feet high, behind which is a long low slope of about 70 feet to the mile. The interpretation of these features is based on the history of the Great Lakes. During the period of retreat of the continental glacier, the ice front at one time blocked the present outlet (the northwestward-flowing St. Lawrence River). This natural ice dam raised the level of all the Great Lakes, and the waves of the older and larger Lake Erie washed against the limestone cliff or escarpment which runs parallel to the road connecting Euclid, Collamer, and East End. A long, gently sloping beach or platform, composed of the products of wave erosion and the sediment brought in by rivers, was built out beneath the lake for over two miles from the foot of the escarpment. With the retreat of the continental ice sheet, the St. Lawrence outlet was unblocked and the lake waters subsided to their present level. Thus the old line of cliffs and the former underwater beach are now standing above the present water level. The lake waves are now engaged in cutting back the bluffs along the lake shore, and have begun the construction of a new beach and underwater terrace. In the case of the old terraces and cliffs, it is fairly obvious that their relative "uplift" is due to the subsidence of the former level of the waters of Lake Erie. The ocean is the ultimate level for all "running" water. It is not necessary to postulate that the lake shore has risen or has been uplifted relative to the present lake level, although such could have been the case. When we speak of raised or uplifted terraces, we mean that they have been raised or uplifted relative to the present level of the adjacent, "standing" body of water. Even in the case of uplifted marine terraces, we cannot always be sure

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whether the land has gone up or the surface of the sea has gone down: whether there have been differential movements in opposite directions or differential movements in the same direction.

INSTRUCTOR'S REMARKS



## GEOLOGY MANUAL

### LABORATORY EXERCISE ON SHORE LINES

#### *List of Undescribed Maps*

Atlantic City, N.J.

Capitola, Calif.

Cayucos, Calif.

Erie, Pa.

Mathews, Va.

Navesink, N.Y.-N.J.

1. For each of the undescribed maps, locate, and discuss the origin of the shore line phenomena.
2. Name the maps which illustrate a coast line of submergence, and describe the stage of the cycle of erosion shown on each map.
3. Study<sup>1</sup> the specimens of marine sediments on the demonstration desk and:
  - a) Classify them according to whether they are of mechanical, chemical, or organic origin.
  - b) Sketch and describe the structures shown in the specimens of sedimentary rocks.
  - c) Classify the specimens according to the depth of water in which they were probably deposited.
4. Be sure that you understand the following terms: ria, fiord, fiard, tied-island, tombolo, cusped bar, barrier beach, lagoon, tidal delta, baymouth bar, hooked spit, lake terrace, marine terrace, bayhead bar.

<sup>1</sup> See previous exercise on sedimentary rocks.

#### INSTRUCTOR'S REMARKS

1

# LABORATORY EXERCISE ON SHORE LINES

NAME

DIVISION

DATE



| NAME | DIVISION | DATE |
|------|----------|------|
|------|----------|------|



## APPALACHIAN TOPOGRAPHY

If time permits, and the student has a sufficient knowledge of folded structures, he may consider the relation of structure to topography, as illustrated by the Bristol, Va., sheet. Such a study is valuable because it:

- 1) Shows the interrelation of stage, structure, and process.
- 2) Comprises the complete, topographic history of a single area.
- 3) Shows what can be done with a topographic map without the geologic map.

The Appalachian region is particularly interesting because it was here that geologists first learned some of the secrets regarding mountain building (orogeny) and the evolution of land forms (physiography). Any student who is interested in geology should plan to make a pilgrimage to the northern or southern Appalachians, as they illustrate in a remarkably clear and interesting way many of the facts and theories which have been studied in this course.

### *Described Map*

Bristol, Va.

(PARALLEL RIDGES, TRELLIS DRAINAGE, ENTRENCHED MEANDERS,  
CYCLES OF EROSION, SINK HOLES, UNDERGROUND STREAMS)

### STRUCTURE:

The lineal character of the topography shown on a large part of this map suggests differential erosion in a series of alternating hard and soft formations. By comparison with the geologic map of North America, it will be seen that most of the Bristol quadrangle lies within the Appalachian Mountains Province, a region of folded sedimentary rocks which have been denuded (truncated by erosion) in such a way as to produce adjacent bands of unequal hardness and solubility. This particular section of the Appalachians has been selected because it is particularly free from faults and therefore is not too complicated for the elementary student. The valleys have been developed in the softer and more soluble formations (limestone) between the more resistant (sandstone) ridges. The absence of parallel ridges and valleys in the upper left hand



corner of the map suggests a more uniform composition of the bed rock. By comparison with the geologic map of North America, it will be seen that this area is on the border of the Appalachian Plateau Province where the beds have not been folded, and therefore "structure" is not so important a factor in the modification of the topography.

#### RIVER EROSION:

Although the topographic pattern of the greater portion of this region has been etched by running water, both on the surface and underground, yet the "stream patterns" have been largely controlled by the structure of the formations as previously described. Supposing the map had been printed without any contours, the peculiar "stream patterns" alone would strongly suggest a region which had been subjected to the Appalachian type of folding. The major streams, though meandering, run roughly parallel to the well-defined ridges. As these major streams deepen their limestone valleys, the resulting slopes of the harder and more resistant sandstone valley walls become the subsequent water sheds for numerous, well-spaced but short, tributary streams which enter the main streams at right angles. This style of stream pattern is called trellis drainage, and is easily distinguished from the digitate drainage previously studied.

#### CYCLE OF EROSION:

*1st Cycle.* The accordance level of Clinch Mountain and Copper Ridge suggests the remnants of a former peneplain (nearly a plain) now uplifted (2500 feet).

*2nd Cycle.* The accordance level of many of the hills at elevations from 2000 to 2200 feet (Moccasin Ridge, Walker Mountain, Beek Ridge, etc.) suggests that a second lower peneplain was partially developed in the more easily eroded limestones of the valleys, the hard sandstone ridges being only slightly affected. Although, as stated, this second cycle was only partially completed, the major streams had sufficient time to cut to local base level and become meandering.

*3rd Cycle.* A third cycle of erosion has just begun. This is indicated by the entrenched meanders which are incised in the partial peneplain of the second cycle. Note the spurs several hundred feet high between the meanders of Clinch River. Thus the major rivers of this region are interpreted as having de-

veloped a broad plain at the level of the second cycle peneplain (now 2000 feet) upon which they meandered in the manner of old age streams. Subsequent uplift of the region initiated the third cycle, rejuvenated the old meandering streams and renewed their power of downcutting. This process is still going on.

Thus we have the anomaly of a river valley exhibiting a youthful transverse profile (steep banks) and an old age pattern (meanders). If we accept the foregoing explanation, and there seems to be none other quite so reasonable, incised or entrenched meanders are excellent evidences of relatively broad and horizontal regional uplift.

#### GROUNDWATER:

In the vicinity of the Clinch River there are two parallel belts of depression and sink holes. Inspection of the rainfall chart of the United States will show that this is a humid country and that therefore the depressions are probably not the result of wind work. Further, most of the sinks have streams flowing into them and sometimes contain small ponds which seldom, if ever, entirely fill the depressions. The structure has shown the probability that a series of folded, tilted and truncated sedimentary beds underlies the region. Limestone is a common member of most sedimentary series, and is slightly soluble in waters carrying  $\text{CO}_2$  dissolved from the atmosphere and from decaying vegetation. With time, groundwater attacks limestones, entering along pores, joints, and bedding planes, and dissolves out sink holes and underground channels and caverns. It therefore seems reasonable to ascribe the row of sinks and depressions to the work of groundwater on a bed of limestone which has a linear outcrop as a result of folding (see section on *structure*). Such is actually the case. It is computed that the southern Appalachians are being denuded through the solution of limestone at the rate of 275 tons per square mile per year. Very commonly within limestone the underground water follows tubular solution channels. Where such channels have a connection with the surface we have springs formed, often of large volume. Note how Sinking Creek (east of Bristol) flows for some distance underground (dotted line). All the drainage entering the sink holes eventually reaches the rivers by underground channels.

#### SUMMARY:

This sheet and the brief discussion of the topography serves

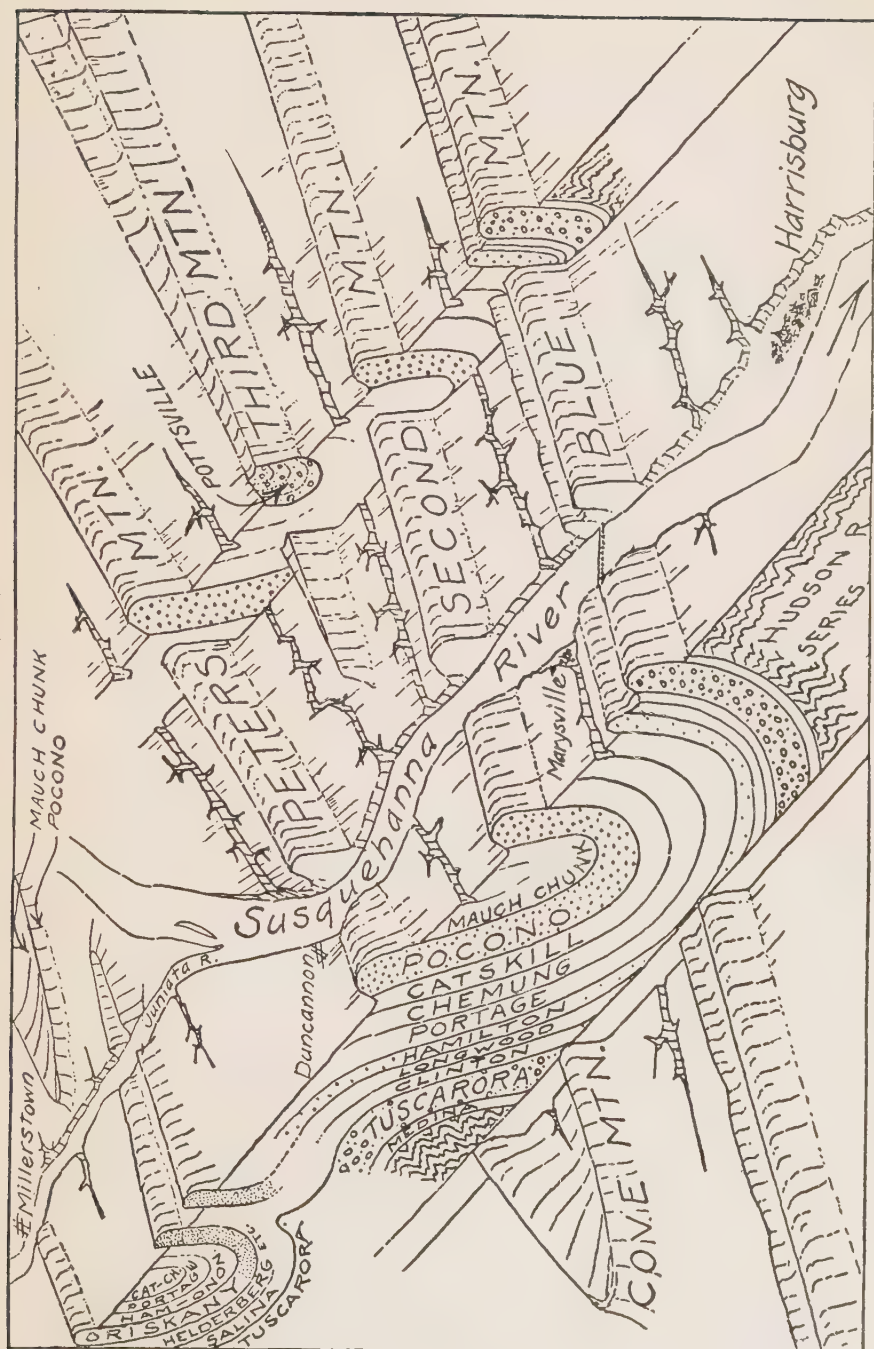
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to illustrate the great complexity and involved history of much of our present scenery. In the course in Physiography the student has the opportunity for further study of the physiographic provinces of the United States and their relation to man. A thorough knowledge of Physiography will be found very helpful to those who intend to take, or are taking, courses in Military Science, Civil Engineering, History, Politics, and Political Economy. As a single illustration of the relation of the physiography of a region to the economic and social development of its inhabitants, notice how the topographic features of Bristol quadrangle control trade and transportation. Compare the Bristol, Va., sheet with the Monterey, Va.-W.Va., sheet.

NOTE: Structural features as shown on maps will be more fully considered in the laboratory work on Historical Geology (2nd Term).

### INSTRUCTOR'S REMARKS

PLATE XVIII



"Block Diagrams," Lobeck (This figure was first published by the N. Y. Academy of Science)



## GEOLOGY MANUAL

### LABORATORY EXERCISE ON APPALACHIAN TOPOGRAPHY LIST OF UNDESCRIBED MAPS

Harrisburg, Pa.

New Bloomfield, Pa.

THE following exercise is intended to illustrate the structural and erosional history in a region of folded, sedimentary rocks. The block diagram, *Plate XVIII*, is a three-dimensional picture of the region covered by the two maps, and shows a Paleozoic series of sedimentary rocks, from the Ordovician period to the Silurian period. The basal beds of the Silurian (Medina formation) are seen to rest uncomformably on the Ordovician (Hudson River Series). The formations were originally laid down in the following order. (Read from the base up):

|                  |                                              |
|------------------|----------------------------------------------|
| 4. Carboniferous | { Mauch Chunk<br>Pocono<br>Catskill          |
| 3. Devonian      | { Chemung<br>Portage<br>Hamilton<br>Longwood |
| 2. Silurian      | { Clinton<br>Tuscarora<br>Medina             |
| 1. Ordovician    | "Hudson River Series."                       |

There is no physical evidence of an unconformity between the Silurian and the Devonian periods or between the Devonian and the Carboniferous periods.

After a careful study of the described map (Bristol, Va.) answer the following questions relating to the area covered by the *New Bloomfield* and *Harrisburg* Quadrangles, and the block diagram:

#### TEST QUESTIONS

1. What is the general structure of the region?
2. What is the evidence that the region was once reduced to base level (a peneplain)?
3. What is the evidence that the region (peneplain) has been uplifted?
4. Has there been more than one cycle of erosion in this region? If so, state how many cycles you can recognize on the maps and the evidence for each.
5. What types of streams seem to be peculiar to a region such as this? Name and locate specific examples.
6. What are the evidences of the work of underground water in this region? Locate and describe specific examples.
7. Describe the complete geologic history of the region from the Ordovician period to the present.

Be sure that you understand the following terms: a) consequent stream, b) subsequent stream, c) antecedent stream, d) entrenched meander, e) trellis drainage or stream pattern, f) peneplain, g) cycle of erosion, h) sink hole, i) wind gap, j) water gap, k) geosyncline, l) anticline, m) syncline, n) differential erosion, o) monadnock.

*GEOLOGY MANUAL*

LABORATORY EXERCISE ON APPALACHIAN TOPOGRAPHY

NAME

DIVISION

DATE





# LABORATORY EXERCISE ON APPALACHIAN TOPOGRAPHY

NAME

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## APPENDIX

The laboratory materials to be used with the Geology Manual are listed below for the convenience of the instructor. The list will also be found useful for those who wish to start a study collection and *teach themselves* the elements of practical geology. The layman will find the following elementary texts useful as supplying the necessary general and theoretical information, which is ordinarily given in the lectures of a general or introductory course of Geology in American Colleges:

"An Introduction to Geology," by William Berryman Scott. Published by The Macmillan Company.

"An Introduction to Earth History," by Harvey Woodburn Shimer. Published by Ginn and Company.

"Field Book of Common Rocks and Minerals," by Frederic Brewster Loomis. Published by G. P. Putnam's Sons.

"The Interpretation of Topographic and Geologic Maps," by Dake and Brown. Published by McGraw, Hill and Company.

"Field Geology," by Frederic H. Lahee. Published by McGraw, Hill and Company.

"Economic Aspects of Geology," by C. K. Leith. Published by Henry Holt and Company.

### LIST OF LABORATORY MATERIALS<sup>1</sup>

#### MINERALS

|               |                |             |
|---------------|----------------|-------------|
| Amphibole     | Flint          | Orthoclase  |
| *Apatite      | *Fluorite      | *Ottrelite  |
| Augite        | *Galena        | Plagioclase |
| *Azurite      | Garnet         | (Pyribole)  |
| Biotite       | Gypsum         | Pyrite      |
| Calcite       | *Halite        | *Pyroxene   |
| *Chalcocite   | Hematite       | *Pyrrhotite |
| *Chalcedony   | *Hornblende    | Quartz      |
| *Chalcopyrite | Kaolin         | Serpentine  |
| Chert         | Limonite       | *Siderite   |
| *Chlorite     | Magnetite      | *Sphalerite |
| *Corundum     | *Malachite     | *Staurolite |
| *Diamond      | (Mica)         | Talc        |
| Dolomite      | Muscovite      | *Topaz      |
| *Epidote      | *Native Copper |             |
| (Feldspar)    | Olivine        |             |

<sup>1</sup> The materials marked with an \* are not absolutely necessary. Feldspar, Mica and *Pyribole* are group names. The topographic maps may be procured from the United States Geological Survey at six cents a piece (when ordered in quantity). Sets of minerals and rocks, for use with this manual, may be procured from Ward's Natural Science Establishment, 84-102 College Ave., Rochester, N.Y.

#### ROCKS

##### *Igneous Rocks*

|              |                 |
|--------------|-----------------|
| *Andesite    | Basalt Porphyry |
| *Anorthosite | *Dacite         |
| Basalt       | *Diabase        |

## APPENDIX

### *Igneous Rocks—Continued*

|                  |                      |
|------------------|----------------------|
| Diorite          | Pegmatite            |
| Felsite          | Peridotite           |
| Felsite Porphyry | *Porphyritic Granite |
| Gabbro           | Pumice               |
| Granite          | Rhyolite             |
| *Granodiorite    | Syenite              |
| *Norite          | *Tachylite           |
| Obsidian         | *Trachyte            |

### *Sedimentary Rocks*

|                         |                         |
|-------------------------|-------------------------|
| Alabaster               | Limestone               |
| Argillite               | *Limestone Breccia      |
| *Argillaceous Limestone | *Limestone Conglomerate |
| Bog Iron Ore            | *Oolitic Dolomite       |
| Calcareous Shale        | Oolitic Hematite        |
| Chert                   | Oolitic Limestone       |
| Conglomerate            | *Rock Salt              |
| Coquina                 | Sandstone               |
| Dolomite                | *Selenite               |
| *Dolomite Breccia       | Shale                   |
| *Dolomite Conglomerate  | *Stalactite             |
| Flint                   | *Stalagmite             |

### *Metamorphic Rocks*

|                   |                                    |            |
|-------------------|------------------------------------|------------|
| Gneiss            | *Porphyritic Gneiss                | Schist     |
| *Injection Gneiss | <sup>1</sup> *Porphyritic Phyllite | Serpentine |
| Marble            | <sup>1</sup> *Porphyritic Schist   | Slate      |
| *Ophicalcite      | <sup>1</sup> *Porphyritic Slate    | Soapstone  |
| *Phyllite         | Quartzite                          |            |

## MAPS<sup>2</sup>

### DESCRIBED MAPS

|                    |                       |                   |
|--------------------|-----------------------|-------------------|
| <i>Arizona:</i>    | Mt. Lyell             | Waukon.           |
| Bright Angel       | Mt. Whitney           | <i>Kentucky:</i>  |
| Echo Cliffs        | Oceanside             | Lockport.         |
| Tusayan.           | Tamalpais.            | <i>Louisiana:</i> |
| <i>Arkansas:</i>   | <i>Connecticut:</i>   | Donaldsonville    |
| Little Rock.       | Hartford.             | Hahnville.        |
| <i>California:</i> | <i>Florida:</i>       | <i>Maine:</i>     |
| Ballarat           | Arredondo.            | Boothbay.         |
| Cucamonga          | <i>Iowa-Nebraska:</i> |                   |

<sup>1</sup> The author uses porphyritic to signify that the rock has phenocrysts (metacrysts). See page 49.

<sup>2</sup> For easy reference the maps may be filed in a large Spring Back Binder (manufactured by The H. R. H. Huntington Co., Myrick Building, Springfield, Mass.). For class use the Described and Undescribed maps should be kept in separate folders.

## APPENDIX

*Maryland:*  
 Drum Point  
 Tolchester.  
*Massachusetts:*  
 Marthas Vineyard  
 Provincetown.  
*Minnesota:*  
 Minneapolis.  
*Missouri:*  
 Marshall  
*Mississippi:*  
 Jonestown.  
*Montana:*  
 Chief Mountain.  
*Nebraska:*  
 Paxton.

*Nevada:*  
 Disaster.  
*New Mexico:*  
 Tularosa.  
*New York:*  
 Elmira  
 Islip  
 Kaaterskill  
 Port Leyden  
 Rochester  
 Watkins  
 Weedsport.  
*North Dakota:*  
 Pingree.

*Ohio:*  
 Euclid.  
*Pennsylvania*  
 Harrisburg  
 New Bloomfield.  
*Tennessee:*  
 Standingstone.  
*Utah:*  
 Gilbert Peak.  
*Virginia:*  
 Bristol  
 Monterey.  
*Washington:*  
 Mt. Rainier Nat'l. Park.

### UNDESCRIBED MAPS\*

*Alaska:*  
 Port Valdez.  
*Arizona:*  
 Diamond Creek.  
*California:*  
 Alturas  
 Capitola  
 Cayucos  
 San Diego  
 Tamalpais.  
*Florida:*  
 Citra.  
*Georgia:*  
 Stapleton.  
*Illinois:*  
 New Haven  
 Renault.  
*Kansas:*  
 Hutchinson  
 Lakin (Geol.)

Lakin (Top.)  
*Kentucky:*  
 Golconda  
 Pikeville.  
*Louisiana:*  
 Baton Rouge.  
*Maine:*  
 Casco Bay  
 Passadumkeag.  
*Minnesota:*  
 Aitkin  
 Deerwood.  
*Montana:*  
 Nyack.  
*Nevada:*  
 Granite Range.  
*New Jersey:*  
 Atlantic City  
 Navesink.

*New Mexico:*  
 Hachita.  
*New York:*  
 Cohoes  
 Skaneateles  
 Clyde.  
*Pennsylvania:*  
 Erie.  
*Texas:*  
 Satsuma.  
*Utah:*  
 Hayden Peak.  
*Virginia:*  
 Mathews.  
*Washington:*  
 Moses Lake  
 Seattle Special.  
*Wisconsin:*  
 Whitewater.

















